

# Preliminary Study of Structural Concrete made with the addition of multi-walled Carbon Nanotubes and Soil Nano Stabilisation 360 System

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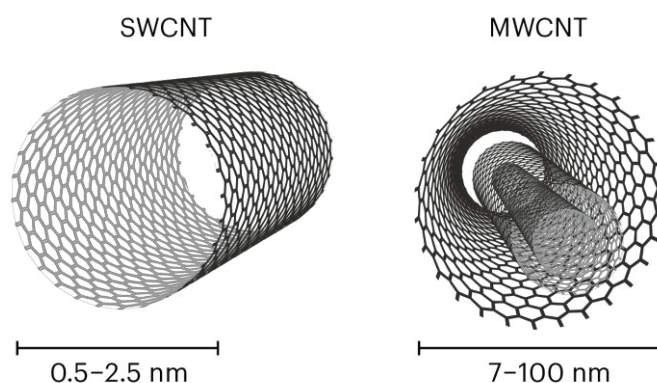
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**Abstract:** The development of nanomaterials in recent years has allowed for the analysis of the possibility of modifying or improving the physical and mechanical properties in concrete manufacturing. Initially, a methodology for the dispersion of nanomaterials was established to homogenize the mixtures. Samples were prepared with varying amounts of MWCNT ranging from 0.05% to 0.25%, in combination with the SNS 360 system at 1% and 2%, alongside a control mix without nano-additions. The samples were fabricated using ordinary Portland cement (OPC) maintaining a water/cement ratio of 0.55. The results indicated a 30% improvement in compressive strength and xx% in tensile strength at 28 days. High compressive strengths were obtained 3 days after its manufacture, acting as an accelerator. At the same time, increasing the percentage of nano materials reduced the slump value and workability. In addition, the permeability decreased significantly compared to standard concrete. Therefore, the concrete mixture with two nanotechnology-based materials demonstrates significant advantages over conventional concrete by being more resistant to compression, traction, exhibiting lower permeability, and achieving high compressive strengths in less time

**Keywords:** Graphene nanotubes, Portland cement, Nanotechnology, Soil Nano Stabilization, Physical mechanical properties

## 1 Introduction

The production of concrete represents one of the primary industrial activities worldwide, solidifying its position as the most important construction material for centuries. This material stands out primarily for its physical and mechanical properties, which facilitate the construction of durable and resilient structures. However, concrete manufacturing entails considerable challenges related to energy consumption, manufacturing processes, environmental effects, and potential implications for human health [1]. Despite the advantages of conventional concrete, it also has limitations, especially in terms of long-term strength and durability. In this context, it is necessary to explore alternatives that can address current engineering problems through research. In this way, we would not only face the challenges mentioned above, but we could also solve part of these problems through innovation in new materials. Nanotechnology has shown its applicability in different fields, such as civil engineering [2]. Recently, the construction industry has been investigating how it can improve its traditional materials with the contribution of this technology. Research has been conducted using water nanobubbles that contribute to increased mechanical properties and durability.[3-4]. An outstanding example is the addition of nanomaterials, such as carbon nanotubes (CNTs), to Ordinary Portland Cement (OPC). This intervention has imparted superior properties to the material, marking a significant milestone in materials science [5-6]. The carbon nanotube (CNT) is a fullerene with a tubular structure derived from hexagonal carbon walls, with nanometric dimensions in diameter and micrometric dimensions in length[7]. It is primarily distinguished in two variants: single-walled (SWCNT), with a single layer of graphene, and multi-walled (MWCNT), composed of multiple concentric layers of graphene[8-11] (Figure 1).



**Figure 1.** Conceptual illustration visually depicting single-walled carbon nanotubes (SWCNT) and multi-walled carbon nanotubes (MWCNT). [12]

The MWCNT, due to its excellent mechanical properties and conductivities, has shown to enhance those of cementitious composites in various applications [13]. Recent research underscores that the integration of MWCNT into cementitious matrices induces notable transformations in their inherent properties. For instance, an increase in compressive strength has been observed, ranging between 20% and 41% [14-19]. Regarding flexural strength, data suggest enhancements ranging from 25% to 33% [20-25]. In the context of tensile strength, a variable of utmost importance, reported advancements fall within the range of 20% to 31% [15], [26-28]. Simultaneously, MWCNT-reinforced composites have demonstrated increased resistance to freeze-thaw cycles, optimizing their durability within a spectrum ranging from 26% to 57% [23-33]. Concerning permeability, results show a substantial reduction, directly favoring the service life of structures [34-39]. Global durability, on the other hand, has experienced notable strengthening, exhibiting greater resistance in the presence of sulfates and under low-temperature conditions [40-43]. In terms of fire resistance, it is noteworthy that concrete enriched with MWCNT exhibits a significant increase in its mechanical properties when reaching temperatures above 300°C, accompanied by reduced flame spread, contributing to resilience and structural safety [44-48].

Simultaneously, the SNS 360 System stands out as an advanced solution in soil nano-stabilization. Comprised mainly of cationic surfactants of plant origin, the system presents two essential chemical components, a liquid nano formulation (NLF), and another solid nano formulation (NPF). Various studies have confirmed their ability to enhance the physical and mechanical characteristics of native soils, reaching optimal levels of stabilization. Their action focuses on reducing the surface tension of water in the fine soil particles, thus limiting their wetting ability [49]. Although its original development was focused on soil stabilization, this material has demonstrated its versatility by finding prominent applications in various fields of civil engineering, providing relevant solutions in large-scale projects [50-61]. An emerging hypothesis suggests that by combining the waterproofing properties of the SNS 360 with the addition of multi-walled carbon nanotubes (MWCNT), we would obtain concrete with superior strength and durability.

This work focuses on studying the physical and mechanical properties of structural concrete designed for a specific strength of 21 MPa from mixtures incorporating different percentages of Graphene Nanotubes and the SNS 360 System. This study aims to establish the combined effects of these nano-additions.

## 2 Materials and methods

### 2.1 Cement and Aggregates

For the preparation of the samples in this investigation, Ordinary Portland Cement (OPC) was used as the binding agent, in accordance with ASTM C150 [62]. The physicochemical characteristics of this cement are detailed in **Table 1**. It is worth mentioning that the aggregates selected for this study are in accordance with ASTM C136 [63].

**Table 1.** Physicochemical characteristics of the cement

Tests	Type	Value	Unit	Test standards	Results	Ref
<b>Chemical Requirements</b>						
MgO	Max	6.0	%		2.1	
SO <sub>3</sub>	Max	3.0	%	ASTM C114	2.8	[88]
Loss on ignition	Max	3.5	%		3.1	
Insoluble waste	Max	1.5	%		0.6	
<b>Physical requirements</b>						
Air content	Max	12	%	ASTM C185	8	[89]
Fineness, specific surface	Min	2600	cm <sup>2</sup> /g	ASTM C204	4000	[90]
Autoclave expansion	Max	0.80	%	ASTM C151	0.07	[91]
<b>Compressive strength</b>						
3 days	Min	12.0	Mpa		29.4	
7 days	Min	19.0	Mpa	ASTM C109	36.6	[92]
28 days	Min	28.0	Mpa		45.3	
<b>Vicat Setting Time</b>						
Initial setting	Min	45	Minutes	ASTM C191-13	139	[93]
Final setting	Max	375	Minutes		250	

The properties of fine and coarse aggregates are presented in Table 2, Table 3; Figure 2, Figure 3.

**Table 2.** Sieve analysis of fine aggregates

Sieve Pulg.	Sieve (mm.)	Retaining Weight	Comulative retaining	Passing	Passing (%)	ASTM C33 requirement	
1/2"	12.700	0	0.0	0.0	100.0	100	100
3/8"	9.500	4.04	0.8	0.8	99.2	100	100
Nº 04	4.750	19.01	3.9	4.7	95.3	95	100
Nº 08	2.360	31.92	6.5	11.2	88.8	80	100
Nº 16	1.180	81.01	16.5	27.7	72.3	50	85
Nº 30	0.600	92.028	18.7	46.4	53.6	25	60
Nº 50	0.300	108.91	22.2	68.6	31.4	10	30
Nº 100	0.150	58.3	11.9	80.4	19.6	2	10
fund		104.822	21.3	101.8	-1.8		

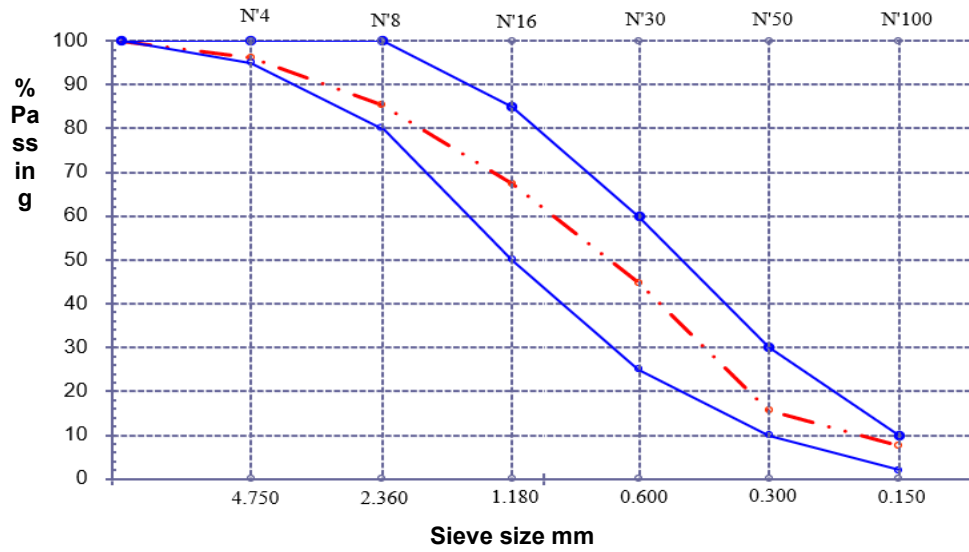


Figure 2. Gradation curve of fine aggregates.

Tabla3. Sieve analysis of coarse aggregates

Sieve Pulg.	Sieve (mm.)	Retaining Weight	Comulative retaining	Passing	Passing (%)	ASTM C33 requirement	
2"	50.00	0.0	0.0	0.0	100.0		
1 1/2"	38.00	0.0	0.0	0.0	100.0	100.0	100.0
1"	25.00	7.0	0.1	0.1	99.9	90.0	100.0
3/4"	19.00	997.0	14.3	14.4	85.6	40.0	85.0
1/2"	12.70	4250.0	61.2	75.6	24.4	10.0	40.0
3/8"	9.52	1360.0	19.6	95.2	4.8	0.0	15.0
N° 04	4.75	330.0	4.7	99.9	0.1	0.0	5.0
N° 08	2.36	0.0	0.0	99.9	0.1	0.0	0.0
N° 16	1.19	0.5	0.0	99.9	0.1	0.0	0.0
Fondo		5.6	0.1	100.0	0.0		

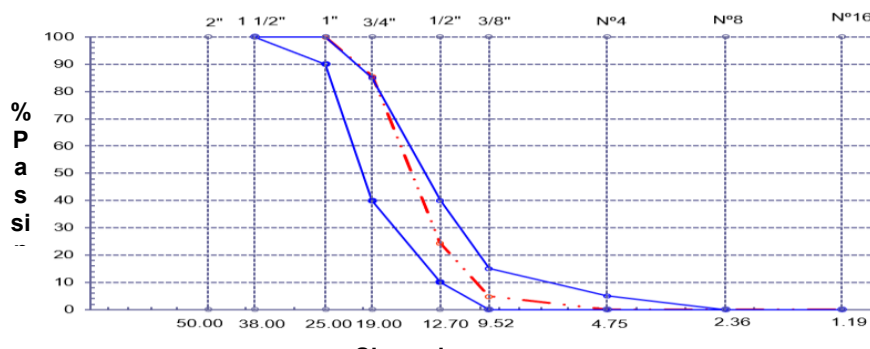


Figure 3. Gradation curve of coarse aggregates.

## 2.2 Nano-Additions

Hydroxylated multi-walled carbon nanotubes (MWCNT) in powder form were used. The manufacturer's datasheet from Nanjing XFNANO Materials Tech Co.,Ltd does not establish toxic properties for living organisms or the environment. The physical specifications of these nanotubes are detailed in **Table 4**. On the other hand, SNS 360 is a plant-based surfactant agent; its relevant properties are found in **Table 5**.

**Table 4.** Properties of carbon nanotubes (MWCNT)

Parameters	Valor
Outer diameter	10-30 nm
Inner diameter	5-10 nm
Tube length	10-30 $\mu$ m
C content	>95 wt%
Specific surface area	>110 m <sup>2</sup> /g
Apparent density	0.14 g/cm <sup>3</sup>
Tap density	~2.1 g/cm <sup>3</sup>
Conductivity	>100 S/cm

**Table 5.** Properties of Soil Nano Stabilization (SNS 360)

Characteristics	Specification	Analytical Method
Appearance/color	granulated solid	Visual
Color	Gray	Visual
Density at 20°C	0.84 - 0.92 g/ml	Maquilador Method
pH (70°C)	5.5 - 7.5	Maquilador Method

## 2.3 MWCNT Dispersion Method

The proper dispersion of CNT (carbon nanotubes) is vital in determining the characteristics of nanocomposites. These nanomaterials tend to aggregate due to attractive forces, such as Van der Waals forces, which complicates achieving a uniform distribution in the mixture [64-69]. The same difficulty arises when attempting to disperse these nanomaterials in cement-based compounds. Attempting to mix CNT directly into cement paste while mixing is not practical, as the cement begins to thicken rapidly after water addition [70-74]. To fully utilize the properties of these nanomaterials, an effective dispersion method is needed to counteract their natural tendency to aggregate. A common technique is ultrasonication, often in combination with other methods [75-79]. The effectiveness of this technique depends on various factors, such as duration, type of ultrasonic device, and the quality and quantity of MWCNT (multi-walled carbon nanotubes) used.

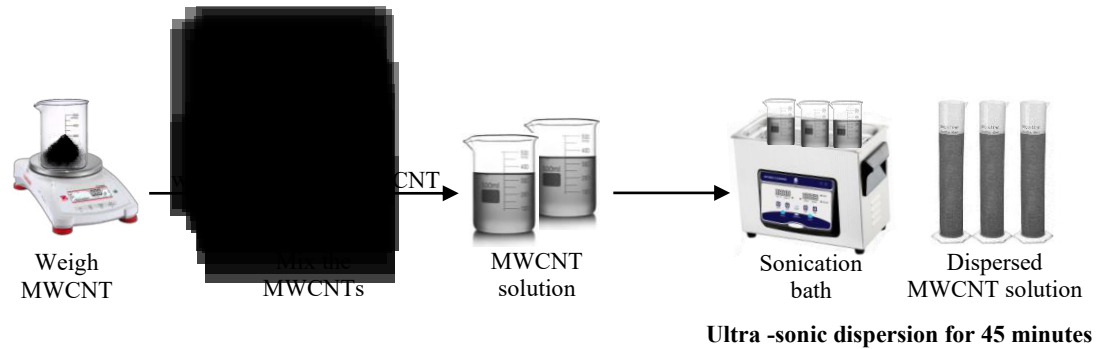
In the research, mixtures have been established using different amounts of MWCNT relative to the weight of the cement, and a soil stabilizer, SNS 360, has been used at concentrations of 1% and 2%. Detailed specifications of these mixtures can be found in **Table 6**.

**Table 6.** Proportions For Concrete Mixes with MWCNT And SNS 360

Mixes	Ratio	Cement	SNS 360	MWCNT
	w/c	Kg/m <sup>3</sup>	%	%
PI-001	0,55	460	-	-
PI-002				0.10%
PI-003	0,55	460	1%	0.25%
PI-004				0.05%
PI-005				0.05%
PI-006	0,55	460	2%	0.10%
PI-007				0.25%

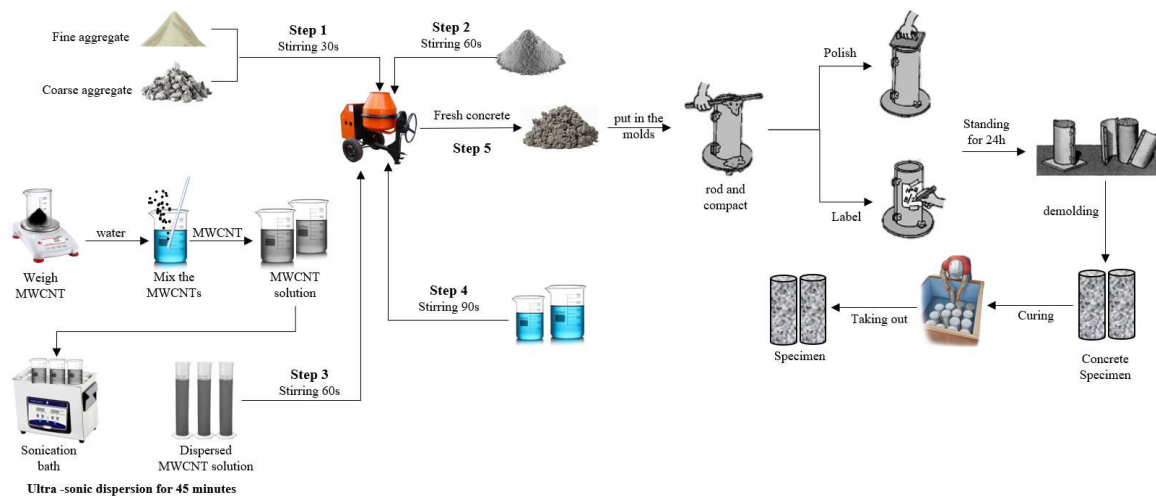
### 2.3 Sample Preparation

To prepare the mixtures, MWCNT were first weighed and added to water, briefly stirred with a glass rod to achieve initial predisposition. Subsequently, ultrasonication was applied to ensure proper dispersion, operating the device at a power of 120 W and a frequency of 40 kHz for 45 minutes at a temperature of 35°C. **Figure 4** illustrates this mixing process in action.



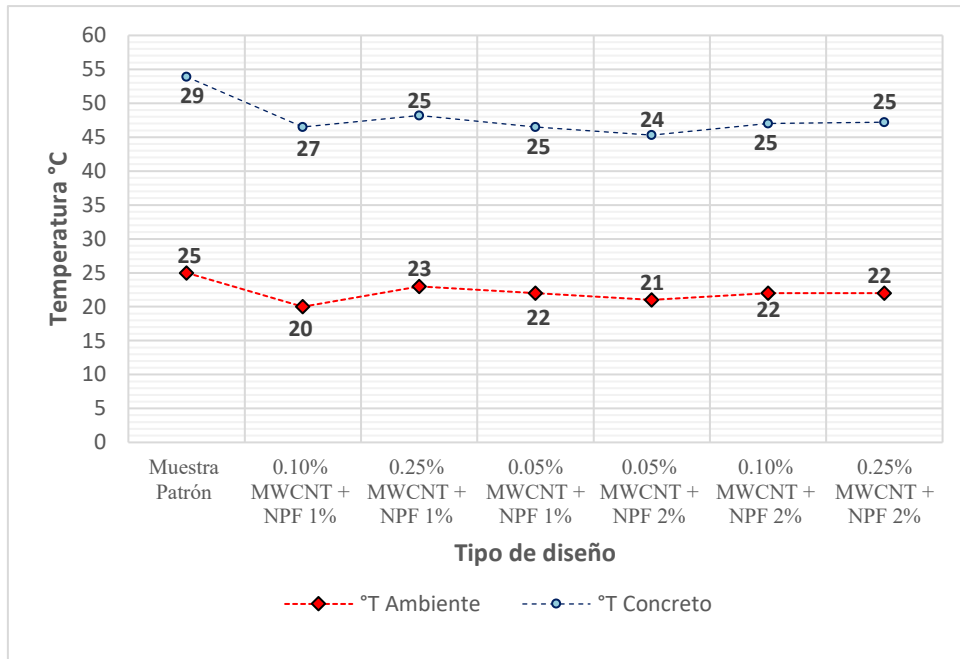
**Figure 4.** MWCNTs dispersion procedure.

The MWCNT, except in the standard mixture without additions (PI-001), were dispersed using ultrasound in 20% of the mixing water for one hour to achieve homogeneous dispersion. **Figure 5** shows the exact process of concrete preparation. Then, the concrete was poured into cylindrical molds of 6"x 12" and prisms of 6"x 6"x 22" to evaluate its mechanical properties. Simultaneously, a physical evaluation of fresh concrete was conducted. Finally, molding and curing of the samples were carried out following ASTM standards C109 [80] and C348 [81].



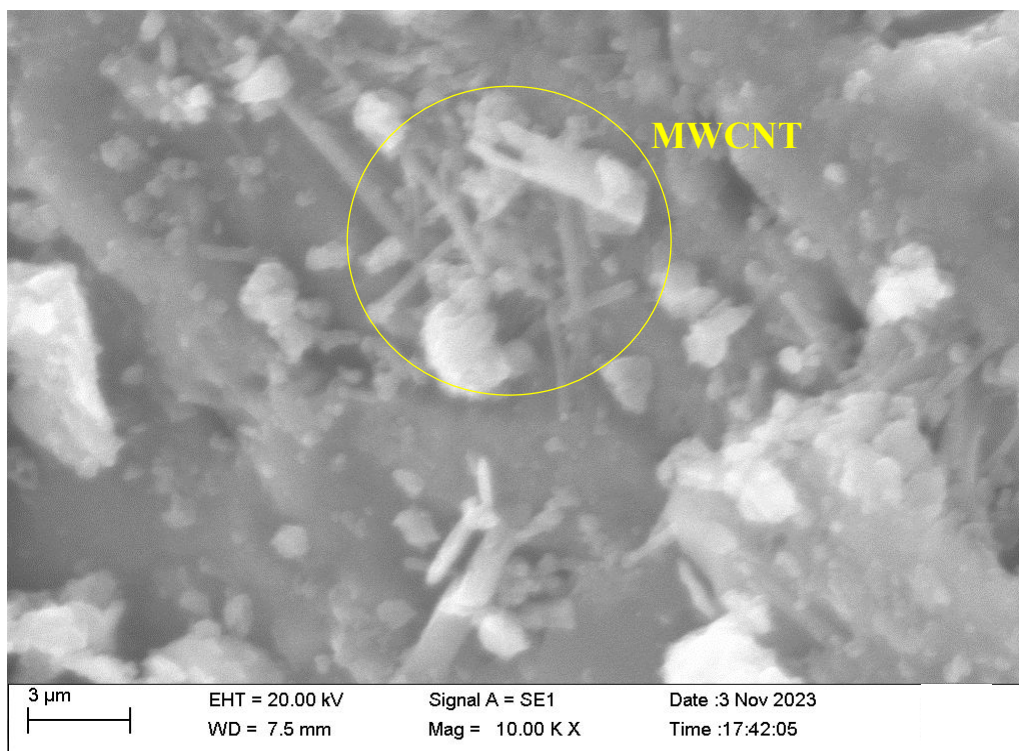
**Figure 5.** Concrete Preparation Process

As indicated earlier in the sample preparation, ASTM standards C109 and C348 have been considered. These standards establish the environmental conditions under which the samples should be prepared. **Figure 6** shows the temperature record during the preparation of each sample design. The ambient conditions did not exceed 32°C.



**Figure 6.** Concrete temperature vs. ambient temperature

**Figure 7** shows a photograph taken with a scanning electron microscope. In the 3µm scale photograph, the homogeneous distribution of the nanotubes can be observed. These materials, due to their nature and size, tend to form agglomerates. It can be seen that each of the nanotubes is individually arranged in the matrix. Additionally, it is also observed that the MWCNTs maintain their intact structure, meaning they have not fractured after the application of ultrasound.



**Figure 7.** scanning electron microscope image of the concrete matrix with MWCNT.

### 3Results

#### 3.1 Physical Properties

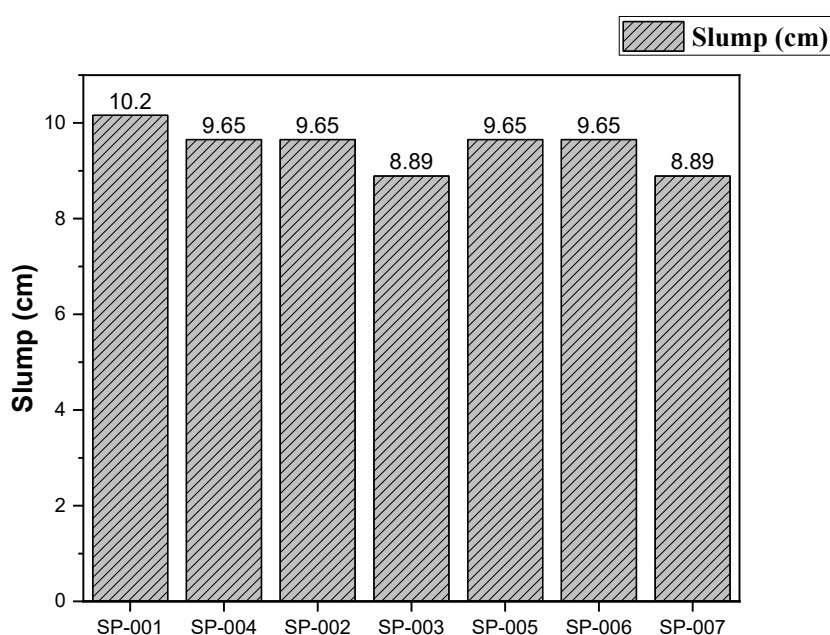
To define the physical parameters of the concrete manufactured with different proportions of additives and the control sample, a total of 320 samples were analyzed in the laboratory.

### 3.1.1 Slump of fresh concrete

The control mixture, PI-AI-001, without additions of CNT or SNS 360, exhibits optimal workability, with a slump exceeding 10 cm. However, upon incorporating CNT and SNS 360 into the mixtures, a decreasing trend in workability is evident. For instance, mixture PI-AI-007, which contains the highest proportion of CNT (0.25%) and 2% SNS 360, shows the lowest slump value, indicating a significant decrease in fluidity compared to the reference mixture, as illustrated in **Figure 8**.

In **Figure 8**, the slump (CM) values for the different percentages of additives and the control sample are displayed. It is observed that the highest slump appears in the control sample with an average value of 10.16 cm, with the highest measured value being 11.32 cm and a minimum value of 9.88 cm, with a standard deviation of 1.2 cm. Conversely, the lowest slump was measured in the sample with the highest percentage of addition, with an average value of 8.89 cm, presenting a maximum value of 9.46 cm and a minimum value of 8.27 cm, with a standard deviation of 1.36 cm. 80 slump measurements have been analyzed.

The difference between the average slump values of the control sample (10.16 cm) and the sample with the highest nano-additive content (8.89 cm) is 1.27 cm. This reduction in workability does not limit the ability to handle samples with lower slump, making it unnecessary to incorporate additives to increase workability.

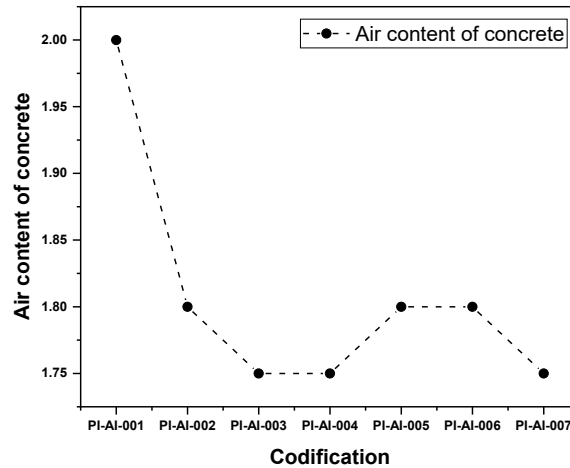


**Figure 8.** Slump values for specimens 0 with MWCNT.

It is observed that by increasing the percentage of SNS 360 in the mixes, there is a partial reduction in workability caused by CNTs. This observation aligns with the hypothesis that water can be trapped between CNT agglomerates, reducing its availability to contribute to concrete flowability. This characteristic is attributable to the high specific surface area of the nanoparticles and their surface tension properties. The hydrophobic nature of CNTs causes water to adhere to them, limiting the interaction with the concrete matrix and thus affecting workability [82-84].

### 3.1.2 Trapped Air Content

Air content in the concrete was determined using the pressure method, according to ASTM C231 [94]. **Figure 9** highlights the behavior of entrapped air for different combinations of additives. The standard concrete, PI-AI-001, exhibits an entrapped air percentage of 2.0%. However, upon incorporating different proportions of MWCNT and SNS 360, a reduction in entrapped air is observed, reaching values close to 1.75% for mixtures PI-AI-003 and PI-AI-007. Contrasting these results with those obtained in **Figure 8**, it is perceived that the standard mixture exhibits superior workability with a slump exceeding 3 inches. Mixtures with additions, on the other hand, show a decrease in fluidity, which could be correlated with the lower amount of entrapped air.



**Figure 9.** Air content of concrete with addition of MWCNTS and SNS 360

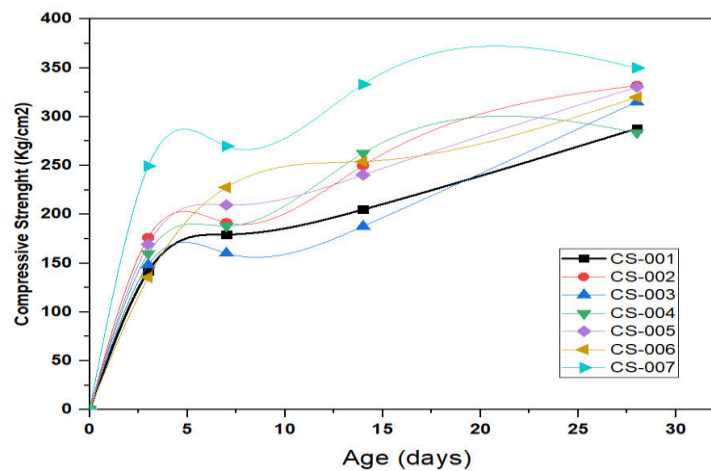
According to the data, mixtures containing 1% of NPF tend to have a lower amount of trapped air compared to those containing 2% of NPF. This observation could be attributed to the interaction of the nanotubes with SNS 360, modulating the amount of air incorporated in the concrete [8]. The interaction between MWCNT and water could reduce the amount of water available for concrete fluidity, directly impacting its workability and the amount of trapped air. These conclusions are consistent with previous studies that have analyzed the behavior of concrete mixtures with nanomodified additives. According to Sldozian et al., the introduction of nanoparticles into concrete can modify the physical and mechanical properties of the material, including workability and trapped air [85-87].

### 3.2 Mechanical properties

#### 3.2.1 Compressive Strength Tests

Results regarding the compressive strength of different concrete mixtures with the addition of MWCNT and NPF are shown in **Figure 10**. The strength was measured at 3, 7, 14, and 28 days of curing. The control mixture (CS-001) exhibits an upward trend in average compressive strength as the curing time is extended, reaching 288 kg/cm<sup>2</sup> at 28 days. This test is conducted following the guidelines of ASTM C-39 standard.

Upon breaking the concrete specimens according to different mixtures and days of breakage, it was observed that the standard deviation values are higher for specimens subjected to simple compression in the early days after the production of the specimens (4.24 Kg/cm<sup>2</sup>) with a maximum breakage value of 146 Kg/cm<sup>2</sup> and a minimum of 140 Kg/cm<sup>2</sup>, and lower for specimens tested at 28 days (1.36 Kg/cm<sup>2</sup>), with a maximum breakage value of 291 Kg/cm<sup>2</sup> and a minimum of 285 Kg/cm<sup>2</sup>.



**Figure 10.** Compressive strength of concrete samples at different ages

When incorporating 0.1% MWCNT + 1% SNS 360 (CS-002), a significant increase is observed, with a value of 332 kg/cm<sup>2</sup> at 28 days. Similarly, mixtures with 0.25% MWCNT + 1% SNS 360 (CS-003) and 0.05% MWCNT + 1% SNS 360 (CS-004) showed strengths of 315 kg/cm<sup>2</sup> and 284 kg/cm<sup>2</sup>, respectively. It is noteworthy that by increasing the amount of SNS 360 to 2%, the strengths tend to approach or exceed the standard, with the most notable case being the mixture with 0.25% MWCNT + 2% SNS 360 (CS-007) reaching 350 kg/cm<sup>2</sup> at 28 days. Comparing the data with previous studies, coherence is found with research where CNT was added to concrete mixes, reporting an increase in strength of approximately 7% to 20% for additions of 0.01% to 0.03% of CNT [25, 85]. Similarly, our study aligns with findings indicating an increase of up to 20% when similar percentages of nanostructured additives are included in concrete mixes.

### Tensile Strength Tests

The tensile strength of various concrete mixes is an essential property that determines their ability to withstand tensile forces without fracturing. In the conducted study, different types of concrete with variations in their compositions were analyzed, as shown in **Table 7**, to understand how the additions of MWCNT and SNS 360 affect their tensile strength during different curing stages (3, 7, 14, and 28 days). This test is carried out following the ASTM C-496 standard [95]

**Table 7.** Effect of MWCNTs and SNS 360 on the compressive and splitting tensile strengths of concrete

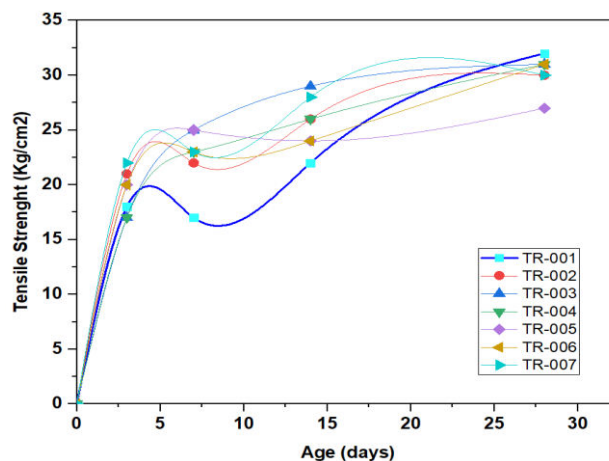
Cod.	Concrete Type	Tensile Strength (kg/cm <sup>2</sup> )			
		3 days	7 days	14 days	28 days
TR-001	Control	18	17	22	32
TR-002	0.10% MWCNT + 1% SNS 360	21	22	26	30
TR-003	0.25% MWCNT + 1% SNS 360	17	25	29	31
TR-004	0.05% MWCNT + 1% SNS 360	17	23	26	31
TR-005	0.05% MWCNT + 2% SNS 360	20	25	24	27
TR-006	0.10% MWCNT + 2% SNS 360	20	23	24	31
TR-007	0.25% MWCNT + 2% SNS 360	22	23	28	30

Initially, it is observed that the control mixture, known as TR-001, exhibited tensile strengths of 18, 17, 22, and 32 kg/cm<sup>2</sup> respectively during the mentioned curing phases. These values serve as a reference point to evaluate the performance of the other experimental mixes.

**Figure 11** represents the results where mixture TR-002, with a composition of 0.10% MWCNT + 1% SNS 360, showed strengths of 21, 22, 26, and 30 kg/cm<sup>2</sup> throughout the curing period. Although it initially exhibits higher tensile strength than the control mixture during the first 14 days, by day 28, the tensile strength of the control mixture surpasses this experimental mixture.

A similar trend is observed in other mixtures, such as TR-003 and TR-004, where despite presenting comparable or even higher strengths in the initial stages of curing, by day 28, they fail to surpass the control mixture. Mixture TR-007, with 0.25% MWCNT + 2% SNS 360, although initially having a high strength of 22 kg/cm<sup>2</sup> at 3 days, ends with a strength of 30 kg/cm<sup>2</sup> at day 28, still lower than the control mixture.

From this observation, it can be inferred that while the additions of MWCNT provide initial benefits in the tensile strength of concrete mixtures, the presence of SNS 360 does not seem conducive to maintaining or improving this strength over time, particularly when compared to the control mixture.



**Figure 11.** Effect of MWCNT and SNS 360% on tensile strength of concrete

**Ensayo Permeabilidad (ASTM D2434-19)**

In the UNE-EN12390-8 permeability test, water penetration was analyzed in different concrete samples. Samples M-01 and M-02, which are standard concrete, showed average penetrations of 24.17 mm and 25.29 mm, respectively, both within the maximum acceptable limit of 50 mm for mass or reinforced elements. Samples M-03 to M-05, with variations of MWCNT, but all with 1% NPF, showed a gradual decrease in penetration: 21.79 mm, 21.09 mm and 20.41 mm. Samples M-06 to M-08, with 2% NPF and MWCNT variations, had penetrations of 19.29 mm, 14.94 mm and 14.14 mm, respectively, values that also meet the mean acceptable limit of 30 mm for bulk or reinforced elements. This trend suggests that increasing MWCNT and SNS 360 improves the impermeability of the concrete. All samples met the established criteria, demonstrating the quality and resistance of the concrete to water penetration.

**Table 8.**Effect of MWCNTs and SNS 360 on water penetration resistance.

Cod. N°	Concrete Type (kg/cm <sup>2</sup> )	Age	Time	Face	Max. penetration (mm)
		(Days)	(72 ± 2 Hours)		Average
PER-01	Standar Mix	28	72	A	<b>24.73</b>
				B	
PER-02	0.1%MECNT + 1%SNS360	28	72	A	<b>21.79</b>
				B	
PER-03	0.25%MWCNT + 1%SNS360	28	72	A	<b>21.09</b>
				B	
PER-04	0.05%MWCNT + 1%SNS360	28	72	A	<b>20.41</b>
				B	
PER-05	0.05%MWCNT + 2%SNS360	28	72	A	<b>19.29</b>
				B	
PER-06	0.10%MWCNT+ 2%SNS360	28	72	A	<b>14.94</b>
				B	
PER-07	0.25%MWCNT + 2%SNS360	28	72	A	<b>14.14</b>
				B	

In the comparison of permeability tests according to Colombian standards NTC 4483 and UNE-EN12390-8, similarities in procedures and results are observed. NTC 4483 uses cylindrical specimens of 6" diameter and 12" height, evaluating permeability at 0.5 MPa. Varying the levels of Carbon Nanotubes (CNT) affects the depth of water penetration: at 28 days, significant reductions are recorded with additions of 5.00%, 10.00%, and 15.00% CNT. In the UNE-EN12390-8 test [84], it is observed that the addition of MWCNT and 1% NPF decreases penetration, while with 2% NPF and different MWCNTs, penetrations are further reduced. These results suggest that the uniform dispersion of nanoparticles improves the homogeneity and compaction of concrete, reducing water penetration. Both tests indicate that certain additions can improve the impermeability of concrete, demonstrating its resistance and quality against water penetration.

**3.3 Chemical Characteristics**

In Figure 12, a photograph taken with a scanning electron microscope at a scale of XXX microns can be observed. Based on the results obtained from the X-ray Diffraction (XRD) test and the spectrometer, a matrix consisting mainly of silica (SiO<sub>2</sub>), alumina (Al<sub>2</sub>O<sub>3</sub>), as well as calcium (Ca<sup>2+</sup>) and magnesium (Mg<sup>2+</sup>) can be observed. Additionally, the structure and arrangement of the nanotubes can be observed. The effectiveness of the dispersion process applied with a thermostatic bath and ultrasound can be verified. It is evident that the nanotubes are intact, with no breakage due to possible excess ultrasound. In **Figure 12** the peaks of the detected elements in the tested sample are shown. A higher percentage of Si, O, Al, Na, and Ca can be observed.

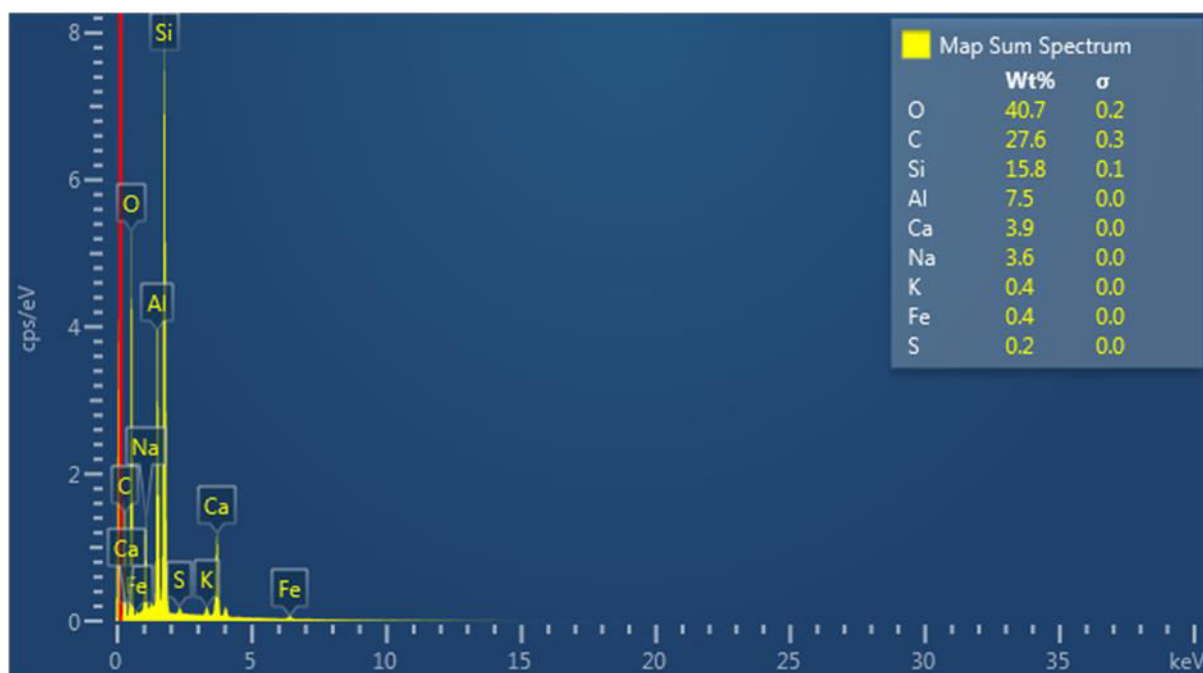


Figure 12. Energy dispersive spectroscopy test on a concrete sample.

## 5 Conclusions

1. In the present investigation, the physical and mechanical properties of concrete made with different percentages of graphene nanotubes (MWCNT) and a nanotechnology-based soil stabilizing system (SNS 360) were studied. The nanomaterials were incorporated into the mix at different times and applying different methodology to ensure their dispersion and homogenization in the mix. The graphene nanotubes were dispersed with ultrasound at a power of 120 W and a frequency of 40 kHz for 45 minutes at a temperature of 35°C. The SNS system was directly incorporated into the mixture.
2. Concrete specimens were manufactured with different percentages of MWCNT and SNS 360. It was observed that the higher the amount of MWCNT, the lower the workability of the fresh concrete.
3. After performing simple compression and indirect tensile tests on the concrete specimens, it was observed that the PI-007 mix caused a 30% increase in compressive strength. In addition, it presents a very high tensile strength at three days (22 kg/cm<sup>2</sup>) and increases up to 30 kg/cm<sup>2</sup> at 28 days. It is observed that the tensile strength of the standard mix exceeds that of the experimental mix. Therefore, the nanomaterials do not contribute to an increase in tensile strength.
4. The concrete samples showed notable variations in compressive strength during the 28-day period. The control sample (CS-001) had a strength of 288 kg/cm<sup>2</sup> at the end of the four weeks. When MWCNT and SNS 360 were incorporated, significant differences were observed. In particular, sample CS-007, with 0.25% MWCNT and 2% SNS 360, showed strengths reaching 350 Kg/cm<sup>2</sup> at 28 days, an increase of 21.5% with respect to the control sample.
5. As for the permeability values, the sample that showed the lowest water penetration in 72 hr of testing was PER-07, which corresponds to 0.25% MWCNT and 2% SNS360. This penetration value is equivalent to a permeability of  $2.27 \times 10^{-7}$  cm/sec, which means that the material developed belongs to the so-called "low permeability media".
6. The developed material is characterized mainly because it is composed of Si, Al, O, Ca and C. According to the X-Ray Diffraction test.

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