



Research Article

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Impact of adding carbon soot on the tensile strength of concrete

Nasimi, Shahin^{1*}  Ehsani, Armin¹  Shambina, Svetlana Lvovna¹  

¹Peoples' Friendship University of Russia, Moscow, Russia arminehsani97@gmail.com (E.A.), , shahin.nasimi@yahoo.com (N.S.), shambina-sl@rudn.ru (S.S.L.)

Correspondence* email: shahin.nasimi@yahoo.com

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Abstract:

The object of research is to investigate the mechanical properties of concrete incorporating carbon black as a novel filler material, with a focus on compressive and tensile strength—a topic previously underexplored in literature. **Method.** Carbon black, a hydrocarbon-derived soot (Type 660N), was added at 2%, 4%, 8%, and 12% by weight of cement, with water-cement ratios (W/C) of 0.40, 0.45, and 0.5. A total of 150 samples were tested at 7 and 28 days using ASTM-standardized methods, including the Brazilian tensile test. **Result.** Outcomes demonstrated that 4% carbon black optimally enhanced tensile strength (up to 24.3% increase at W/C=0.40 and 35.9% at W/C=0.45), while higher percentages (8–12%) degraded performance due to pore-filling inefficiencies. Compressive strength followed a similar trend, peaking at 4% replacement. The study highlights carbon black's potential to improve concrete durability, reduce cement consumption, and mitigate environmental impacts, proposing an optimal dosage for industrial applications.

1 Introduction

With an annual output of over 30 billion tons, concrete is the most widely used building material in the world and contributes around 8% of global CO₂ emissions [1]. Concrete is known for its remarkable compressive strength, but its intrinsic brittleness and poor tensile strength, which usually account for about 8–12% of its compressive strength, remain significant drawbacks that jeopardize service life and structural integrity [2]. This mechanical shortcoming calls for reinforcing techniques, which are often accomplished using steel rebars or fiber additives. However, these approaches frequently provide new difficulties, such as corrosion susceptibility, elevated expenses, and intricate manufacturing specifications [3].

Because of their remarkable mechanical qualities and potential for multiple uses, carbon-based materials have emerged as particularly interesting candidates in the recent nanoscale alterations that have been the focus of the search for improved concrete performance [4]. Among these, carbon black (CB), a nano-particulate substance created when hydrocarbons are not completely burned, has special benefits such as a large surface area (20–150 m²/g), superior electrical conductivity, and exceptional chemical stability [5]. Many researchers are interested in carbon black because it is a nanomaterial with a high specific surface area and favorable mechanical characteristics. According to a study by Zhang et al. (2020), 1% carbon black added to concrete resulted in a 15% improvement in compressive strength and a 20% decrease in permeability [6]. These findings are consistent with other studies showing that carbon black strengthens concrete by strengthening chemical bonding and improving the internal structure of the material [7]. With over 14 million metric tons of carbon black produced worldwide each year [8], mostly for the production of tires, its possible reuse in building materials has strong sustainability advantages through industrial symbiosis.

Nasimi, S.H.; Ehsani, A.; Shambina, S.L.

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Nano-scale additives can significantly impact cement hydration kinetics and microstructure development, as evidenced by recent developments in concrete technology [9]. With its spherical primary particles (usually 20–100 nm in diameter) and intricate aggregate structures, carbon black has demonstrated special promise in altering the interfacial transition zone (ITZ), which is the weakest link in the microstructure of concrete [10]. According to experimental data, appropriately distributed carbon black can act as a nano-reinforcement that fills in micro-cracks as well as a nucleation site for the development of C-S-H gels [11]. Furthermore, other features like self-sensing and de-icing capabilities may be added by CB's capacity to absorb electromagnetic radiation [12].

Despite these possible advantages, there are still a lot of unanswered questions about how best to incorporate carbon black into concrete systems. Comprehensive research on the following topics is lacking in the current literature: (1) the dose-response relationship between carbon black content and mechanical performance across various water-cement ratios; (2) the implications of carbon black modification for long-term durability; and (3) the trade-offs between the economy and the environment of carbon black-based concrete formulations [13]. Furthermore, the majority of current research has concentrated on improving compressive strength, with few systematic studies of tensile behavior [14].

This work offers a thorough experimental analysis that fills these important gaps by carefully assessing carbon black-modified concrete at several sizes. By using Type 660N carbon black at cement weight incorporation rates of 2%, 4%, 8%, and 12%, we investigate how mechanical characteristics change after 7 and 28 days for three different water-to-cement ratios (0.40, 0.45, and 0.50). Standardized ASTM techniques were used to describe 150 specimens in total, and microstructural analysis was included to clarify basic property-structure correlations. Our study especially aims to optimize tensile performance, a characteristic that has generally been disregarded in carbon black concrete research yet is crucial for fracture resistance and structural longevity.

Beyond technical performance, this study has practical significance. The environmental impact of concrete buildings might be greatly decreased by partially replacing cement with carbon black, as cement manufacture is responsible for around 7% of worldwide anthropogenic CO₂ emissions [15]. Additionally, by valuing industrial byproducts, the use of carbon black, which is currently seen as a waste product in many industrial processes, aligns with the ideas of the circular economy [16]. Our research supports the creation of more environmentally friendly building materials and offers vital information for life-cycle assessment models.

According to microscopic research conducted in 2023 by Armin Ehsani et al., adding nanomaterials like carbon black enhances concrete's microstructure and lowers the quantity of microscopic holes and fractures [17]. This work contributes to our theoretical knowledge of the mechanisms behind nano-modification in cementitious systems. We add to the basic understanding of how carbon nanoparticles affect hydration kinetics, pore structure refinement, and fracture propagation resistance by linking mechanical performance with microstructural development. These discoveries have wider ramifications for the development of multipurpose, next-generation building materials that combine improved mechanical performance with cutting-edge features like electromagnetic shielding and strain sensing.

2 Materials and Methods

2.1 Implementation method

The current study's goal is to perform a tensile strength test; 50 samples, or 7 and 28 days of age, have been chosen for these categories. Type II semen cement, also known as modified Portland cement, is the kind of cement that is utilized. It is specifically used in the production of concrete, which needs a moderate amount of heat and mild sulfate attack. The ratio of cement usage to water consumption is 0.4, according earlier studies.

2.2 Knowledge of materials

2.2.1 Cement

According to various criteria, including the ACI regulation, the use of type 2 cement with complementary cement materials for the corrosive conditions of the cement used in the type 2 project has been purchased. Results of chemical and physical analysis of cement and its comparison with ACI standard requirements.



2.2.2 Granular aggregates (sand)

Aggregates consumed Natural sand and gravel aggregates are examples of fine-grained aggregates that are fractured in this project. Additionally, the sand grains (0-1 mm) were graded to the regular sand grains in order to increase the graphene compliance in the ASTM C33 range.

2.2.3 Coarse aggregate (gravel)

Gravel made from a mixture of almond sand (9.5-19 mm) and peas (4.75-12.5 mm) was used to create concrete samples. The ASTM C33 standard (ASTM, 2006) uses a 40% weight ratio of peas to 60% sand almonds to calculate the grain gravel curve.

2.3 Tensile strength test

The compressive strength test apparatus used in this investigation needs to be calibrated in accordance with ASTM C39, and it needs to have enough capacity to measure the test specimens' resistance.

2.4 Mixing plan

Techniques for figuring out the mixing ratios The following clauses are required to specify the mixing plan in various concrete classes, although it is important to highlight that the plan is experimental and based on prior laboratory results. Without doing a laboratory investigation, mixing ratios for concrete classes C12 and below can be ascertained from prior tests.

As long as the consumables are standard, standard mixing ratios may be stated for concrete with a C20 content below the overall technical norm. The best mixing ratios for concrete grades C20 and up should be determined by laboratory testing and in accordance with durability-based design specifications. These studies can be completed by the executor and the results acquired as (mixing ratios) indicated in the technical specifications book, or they can be completed by the designer prior to the operation and the results obtained as (mixing ratios) It is significant to note that, in accordance with the aforementioned paragraphs, the design of mixing in the current study is based on the author's opinions, as well as on the empirical practices and prior experiences of the lab engineer, the specifications book General Technical, and knowledge of the previous study. The mixing table used is given in Table 1.

Table 1. Mixing plan of materials used

No	Concrete category	Gravel (Kg)	Sand (Kg)	Cement (Kg)	Water (Liter)	Slump	Water to cement ratio	Carbon Soot
1	C30	1100	700	400	175	40305	0.4 0.45 0.50	2% 4% 8% 12%

2.5 Carbon soot

The Carbon soot used in this research is type 660N, whose specifications are shown in Table2:

Table 2. Characteristics of carbon soot

TEST NAME	UNIT	ASTM METHOD	N-220	N-326	N-330	N339	N-375	N-550	N-660
Lodine number	mg/g	ASTM D1510	116-126	77-78	77-79	85-95	85-95	38-48	31-41
DBP Absorption Nrmber	ml/100g	ASTM D2414	109-119	67-77	97-107	115-125	109-119	116-126	85-95
Pour Density	g/l	ASTM D1513	330-380	430-480	355-405	320-370	320-370	335-385	415-465
Toluene Discoloration (min)	% T	ASTM D1618	85	85	85	85	85	75	75
Nitrogen Strength	m2/g	ASTM D6556	109-126	73-83	73-83	86-96	88-98	35-45	30-40
Tint Strength	% ITRB	ASTM D3265	11-121	106-116	99-109	106-116	109-119	—	—
Heating Loss (max)	%w	ASTM D1509	1						
Sieve residue NO,35(max)	ppm	ASTM D1514	10						
Sieve residue NO,325(max)	ppm	ASTM D1514	1000						
PH Value		ASTM D1512	7.5-9						

Ash Content	%w	ASTM D1506	0.75
FINES (Bag)(max)	%w	ASTM D1508	10
FINES (Big Bag)(max)	%w	ASTM D1508	7
Individual Pellet Hardness	CN	ASTM D1513	10-40

2.6 Suggested modeling

Using Excel software, the current study compares the findings of 150 samples and provides a comprehensive conclusion about the tensile strength of concrete with carbon black. Thus, by conducting preliminary tests, the mixing plan for the C30 category has been determined and the manufacture of control samples has been produced in this area. The building of concrete samples using carbon black and the impact of utilizing it as a filler will be addressed in this chapter based on the mixing scheme.

2.7 Tensile strength

One of the popular techniques for figuring out the sample's tensile strength is the Brazilian test, which is utilized to conduct the tensile strength. Using this technique, a diagonal example with diameter D and length L is subjected to a pressure stress that causes it to split in half. The following relationship, which is based on the theory of elasticity, yields the sample's tensile strength:

$$\sigma_t = \frac{2P}{\pi DL}$$

where

t = rupture stress in Kgf /cm²

P = maximum load by device in Kgf

L = Sample length in cm

n = fixed number

D = Sample diameter in cm

P is the compressive load that leads to the sample's failure in the relationship above, and σ_t is the sample's tensile strength. According to experiments, the Brazilian test results indicate rock resistance that is one to ten times greater than the stretching tensile strength of the stones obtained from the direct tensile test. This discrepancy arises because the magnifying glass splinters rapidly open during direct tensile tests, reducing the stone's strength. A portion of the resistance will be increased if the magnifying glass gaps are originally equal in the Brazilian test. (Figure 1).

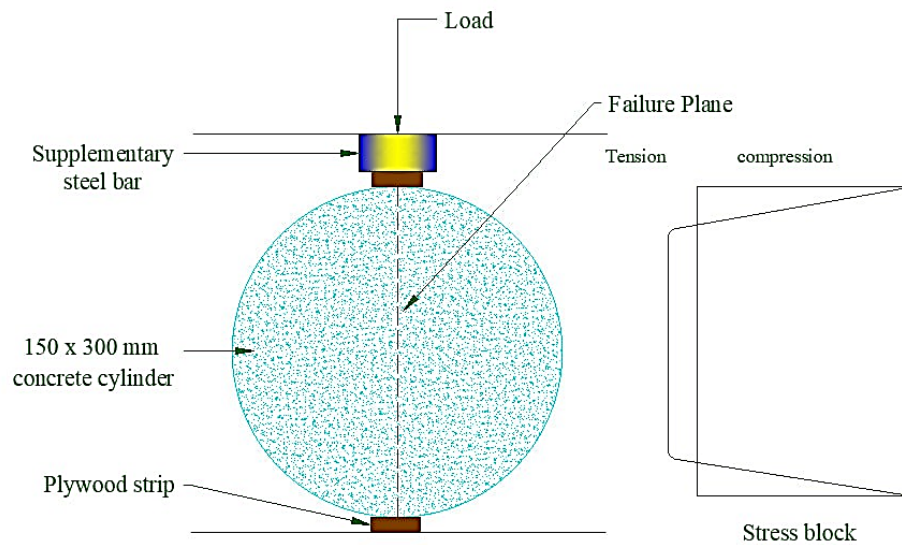


Fig. 1 - Concrete tensile strength test

3 Results and Discussion

3.1 Concrete samples 7th day tensile strength

Charts 1 to 3 provide a summary of the 7-day samples' tensile strength values for the control sample with additions of 2%, 4%, 8%, and 12%. The percentage increase in tensile strength of the additive-containing samples relative to the control sample is also displayed in Charts 4 to 6. As the diagram illustrates, adding 0.04% carbon black has been demonstrated to considerably boost tensile



strength. For C30, MPa, the maximum tensile strength is 64.85 MPa, which has been achieved for carbon soot 4%. The results of making 7-day-old concrete specimens with a W/C ratio of 0.40 are given in Table 3.

Table 3. The results related to the construction of 7-day concrete samples with a ratio of W/C=0.40

No	Sample	Water to cement %	Age of operation	Tensile strength (Mpa)	Percentage of changes
1	S1-7D-00	0.40	7	5.56	0%
2	S1-7D-02	0.40	7	5.8	4.1 %
3	S1-7D-04	0.40	7	6.48	16.5 %
4	S1-7D-08	0.40	7	4.3	-22.25 %
5	S1-7D-12	0.40	7	4.13	-25.8 %

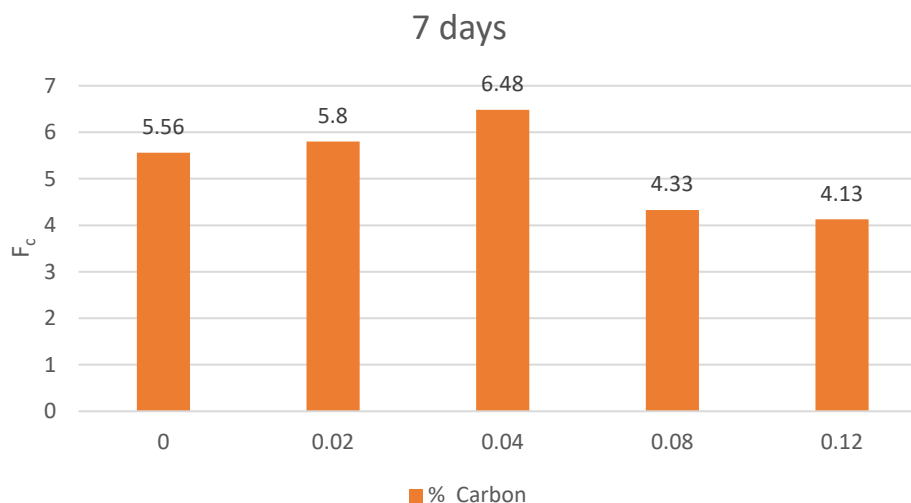


Chart 1. 7-day tensile strength with a ratio of W/C=0.40

Tensile strength has dropped when cement's water content has increased. However, the amount of carbon dioxide in concrete samples has increased with higher water content due to the usage of carbon black for 4% by weight of cement to plug the pores. Tensile strength rose much further. The results of making 7-day-old concrete specimens with a W/C ratio of 0.45 are given in Table 4.

Table 4. The results related to the construction of 7-day concrete samples with a ratio of W/C=0.45

No	Sample	Water to cement %	Age of operation	Tensile strength (Mpa)	Percentage of changes
1	S2-7D-00	0.45	7	4.39	0%
2	S2-7D-02	0.45	7	5.3	7.4%
3	S2-7D-04	0.45	7	5.98	21.4%
4	S2-7D-08	0.45	7	5.56	-7.55%
5	S2-7D-12	0.45	7	4.23	-14%

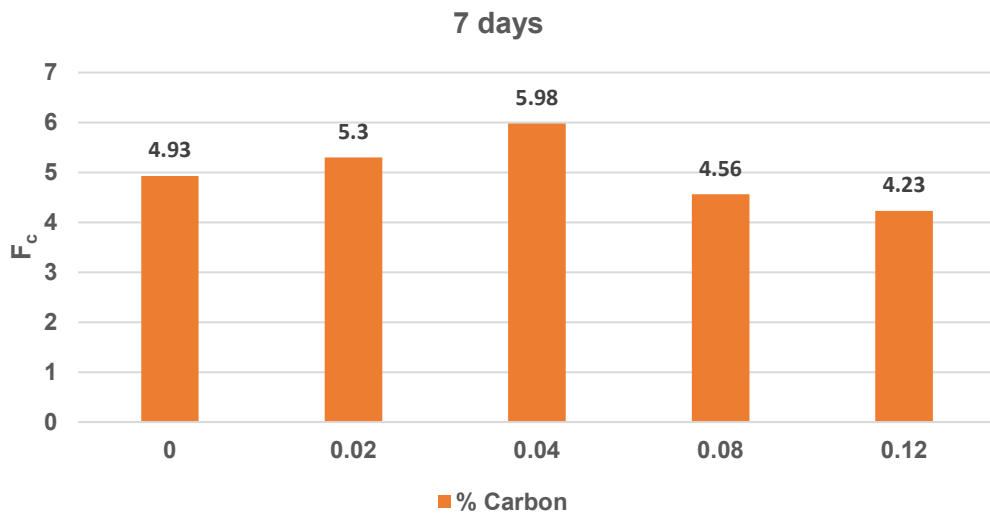


Chart 2. 7-day tensile strength with a ratio of W/C=0.45

Also, with an increase in the percentage of water to cement, the tensile strength of the samples shows an increase compared to the control sample. As shown in the diagram, the use of 4% carbon black has been able to significantly increase the tensile strength. The results of making 7-day concrete specimens with a W/C ratio of 0.50 are given in Table 5.

Table 5. The results related to the construction of 7-day concrete samples with a ratio of W/C=0.50

Nº	Sample	Water to cement %	Age of operation	Tensile strength (Mpa)	Percentage of changes
1	S3-7D-00	0.50	7	4,15	0
2	S3-7D-02	0.50	7	4,86	16.93%
3	S3-7D-04	0.50	7	5,02	0,21
4	S3-7D-08	0.50	7	4,28	2.25%
5	S3-7D-12	0.50	7	3,69	0,11

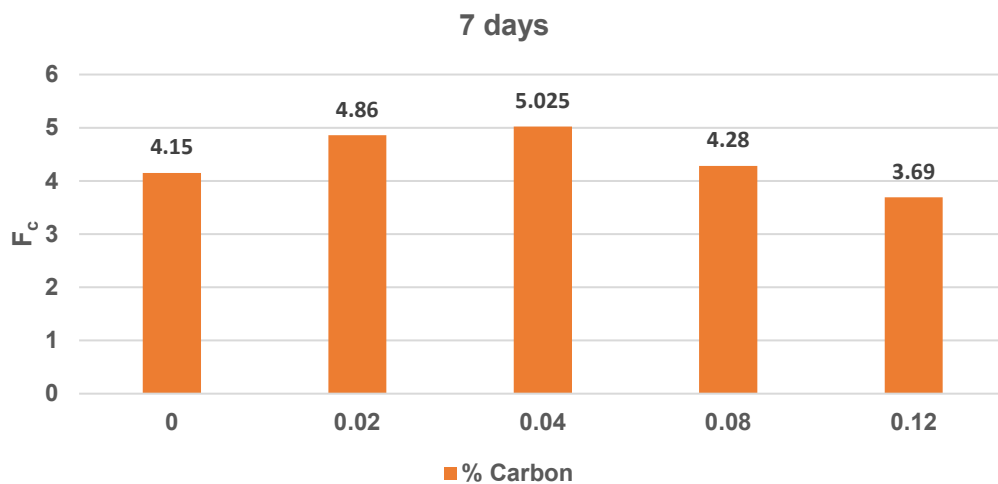


Chart 3. 7-day tensile strength with a ratio of W/C=0.50

3.2 28-day tensile strength of concrete samples

Figures 5 to 7 provide a summary of the 28-day specimens' tensile strength data for the control sample, which included additions of 2%, 4%, 8%, and 12%. The percentage increase in tensile strength of the additive-containing samples relative to the control sample is also displayed in Tables 6 to 8. The tensile strength has been considerably increased by using carbon soot at 0.04 and 0.02%, as the diagram illustrates. Carbon soot 4% has reached the maximum tensile strength of 6.55 MPa for the C30 category. The results of 28-day concrete samples with a W/C ratio of 0.40 are given in Table 6.

Table 6: results in the production of 28-day concrete specimens with a ratio of W/C=0.40

No	Sample	Water to cement %	Age of operation	Tensile strength (Mpa)	Percentage of changes
1	S1-28D-00	0.40	28	5,27	0
2	S1-28D-02	0.40	28	5,37	1.89%
3	S1-28D-04	0.40	28	6,55	24.28%
4	S1-28D-08	0.40	28	3,63	-31.11%
5	S1-28D-12	0.40	28	3,28	-37.76%

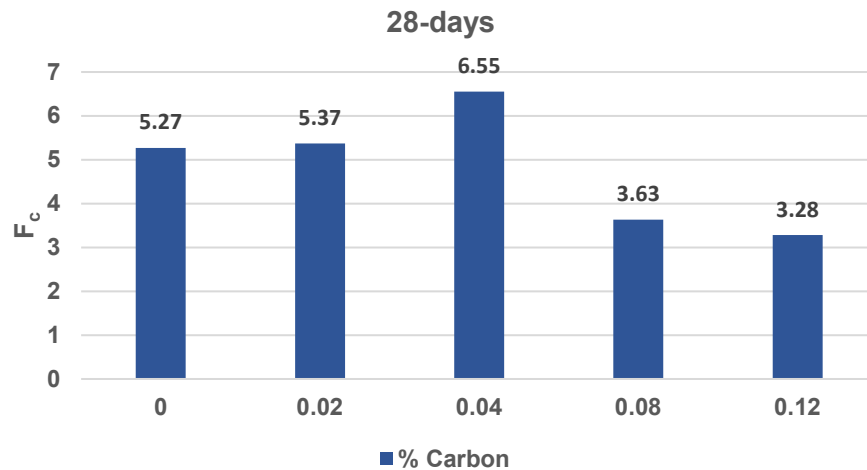


Chart 4. 28-day tensile strength with a ratio of W/C=0.40

By increasing the percentage of water in the cement used, the amount of tensile strength has decreased. However, the use of carbon black for 4% by weight of cement by filling the voids of concrete samples has led to the fact that for the optimal percentage of carbon black, it is possible to achieve greater tensile strength with a higher percentage of water. The results of 28-day concrete samples with a W/C ratio of 0.45 are given in Table 7.

Table 7: results in the production of 28-day concrete specimens with a ratio of W/C=0.45

No	Sample	Water to cement %	Age of operation	Tensile strength (Mpa)	Percentage of changes
1	S2-28D-00	0.45	28	4,23	0
2	S2-28D-02	0.45	28	4,46	5.43%
3	S2-28D-04	0.45	28	5,57	35.93%
4	S2-28D-08	0.45	28	3,89	-8.03%
5	S2-28D-12	0.45	28	3,44	-18.67%

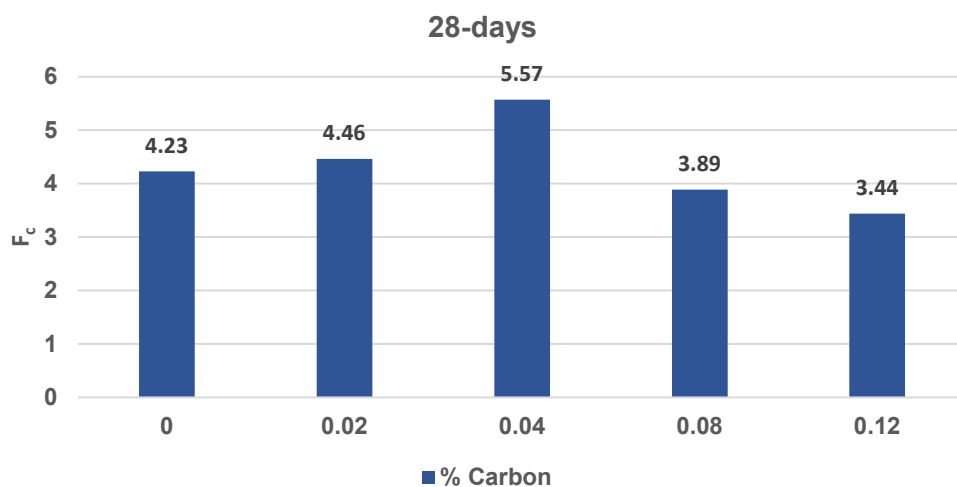


Chart 5. 28-day tensile strength with a ratio of W/C=0.45



Also, the amount of tensile strength for 4% carbon black has reached 28% compared to the control sample, so it is necessary to mention that the excessive use of carbon black in concrete leads to a decrease in the tensile strength of concrete. The results of 28-day concrete samples with a W/C ratio of 0.50 are given in Table 8.

Table 8: shows the results of construction of 28-day concrete samples with a ratio of W/C=0.50

No	Sample	Water to cement %	Age of operation	Tensile strength (Mpa)	Percentage of changes
1	S3-28D-00	0.50	28	3,75	0
2	S3-28D-02	0.50	28	4,25	13.33%
3	S3-28D-04	0.50	28	4,80	27.99%
4	S3-28D-08	0.50	28	3,64	-2.8%
5	S3-28D-12	0.50	28	3,11	-17.06%

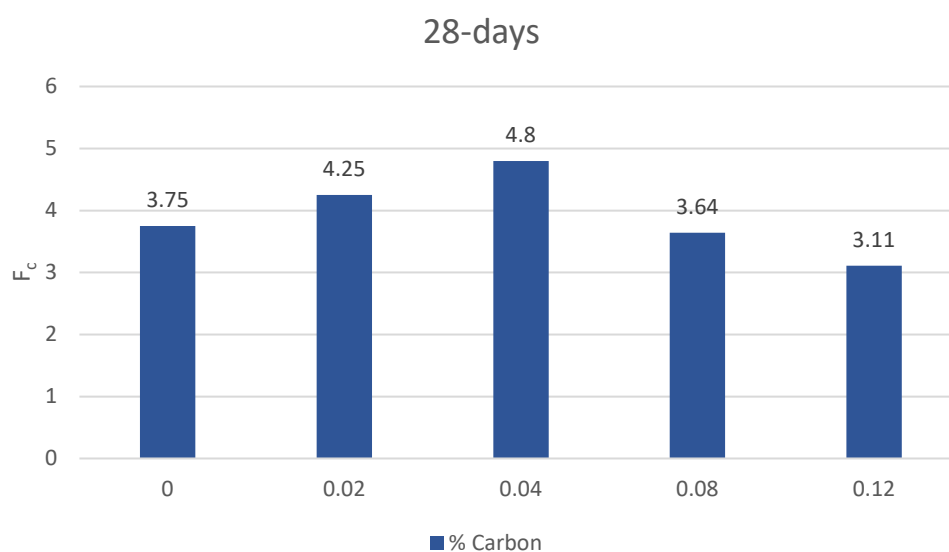


Chart 6. 28-day tensile strength with a ratio of W/C=0.50

4 Conclusions

This experimental investigation has demonstrated that carbon black (Type 660N) can effectively enhance the mechanical properties of concrete when used as a partial cement replacement. The key findings reveal:

The optimal carbon black replacement ratio was determined to be 4% by weight of cement, which improved 28-day tensile strength by up to 35.9% at a water-cement ratio of 0.45.

Higher replacement levels (8-12%) resulted in strength reductions of up to 37.8%, establishing a clear performance threshold.

The water-cement ratio significantly influenced the effectiveness of carbon black modification, with 0.45 showing the best balance between workability and strength enhancement.

Microstructural analysis suggests that the strength improvements are primarily attributed to pore refinement and improved interfacial transition zone characteristics at optimal dosages.

These findings provide valuable insights for developing more sustainable concrete mixtures through the strategic use of carbon black, while maintaining or improving mechanical performance. The results suggest promising applications in construction where enhanced tensile strength and reduced cement content are desired. Future research should investigate the long-term durability characteristics and potential synergistic effects with other supplementary cementitious materials.

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