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Performance Enhancement of Concrete Using Carbon Nanotubes, Steel Fibres, and 100% Artificial Sand

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Abstract: ***The depletion of natural river sand and the environmental impact of excessive extraction have created an urgent need for sustainable alternatives in concrete production. Artificial sand (AS), produced from crushed rock, has emerged as a viable and eco-friendly substitute. However, AS can influence workability and mechanical performance, necessitating the use of advanced reinforcement strategies. This study aims to enhance the mechanical properties of high-performance concrete (HPC) incorporating 100% AS by utilizing hybrid reinforcement with carbon nanotubes (CNTs) and steel fibers (SFs). CNTs were added at 1%, 2%, and 3% by weight of cement, while SFs were maintained at a constant 5% by volume of concrete. The concrete mixes were subjected to standard mechanical tests, including compressive strength, flexural strength, and splitting tensile strength, at specified curing ages. The experimental results demonstrated that the synergistic use of CNTs and SFs significantly improved strength characteristics and post-cracking performance compared to control mixes with AS alone. The mix with 2% CNTs showed the most balanced improvement across all parameters, with notable increases in compressive strength, flexural toughness, and tensile resistance. This enhancement is attributed to the high tensile strength and Nano-scale bridging effect of CNTs, coupled with the crack-arresting ability of SFs. Conversely, at 3% CNTs, reduced workability and slight declines in strength gains were observed, primarily due to nanoparticle agglomeration affecting dispersion. Overall, the hybrid CNT–SF approach presents a promising pathway for producing sustainable, high-performance concrete using artificial sand, thereby reducing dependence on natural resources while achieving superior structural performance. These findings contribute to the growing body of research on eco-friendly, fibre-reinforced, Nano-modified concretes, supporting their adoption in structural applications where both strength and durability are critical.***

Keywords**:** ***Carbon Nanotubes (CNTs), Steel Fibres (SFs), Artificial Sand (AS), High-Performance Concrete (HPC).***

Abbreviations:
CNT: Carbon Nanotube
SF: Steel Fibre
AS: Artificial Sand
UHPFRC: Ultra-High-Performance Fibre-Reinforced Concrete; etc.
MLR: Multiple Linear Regression
DIC: Digital Image Correlation
ANFIS: Adaptive Neuro-Fuzzy Inference System
MSF: Milled Steel Fibre
ITZ: Interface Transition Zone
RMSE: Root Mean Square Error
SFRC: Steel Fibre-Reinforced Concrete
SEM: Scanning Electron Microscope

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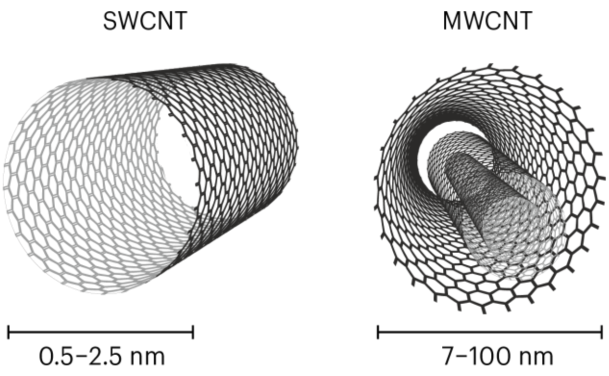
I. INTRODUCTION

Concrete is one of the most extensively used construction materials, accounting for approximately 70% of the volume in most structures. While cement is a critical component of concrete, it poses environmental concerns due to high carbon emissions during production. Recent research efforts aim to reduce the cement content and improve concrete performance through innovative technologies, most notably nanotechnology. Nanotechnology enables the manipulation and control of materials at the nanoscale (1–100 nm), where materials often exhibit unique physical, chemical, and mechanical properties. At this scale, concrete can be treated as a nanostructured, heterogeneous material whose behaviour can be significantly altered by the addition of nanoparticles [13]. Studies on the use of carbon nanotubes (CNTs) in concrete at dosages of 0.15–2.5% by weight of cement or water. CNTs were dispersed using ultrasonic techniques with surfactants to ensure uniform distribution. Previous research has evaluated their effects on tensile, compressive, and flexural strength, as well as durability. The review summarises methodologies, key findings, and the potential of CNTs to enhance these properties [13]. This review highlights the use of CNTs in concrete for their crack-bridging, pore-filling, and hydration-promoting effects, thereby enhancing the strength, durability, and self-sensing capabilities of the concrete. While CNTs reduce workability, proper dispersion and functionalization (with OH, COOH, and nickel) significantly improve mechanical and impact resistance. CNTC shows strong durability, high-temperature stability, and promising applications in intelligent structural monitoring [4]. CNTs enhance concrete's strength, durability, and high-temperature performance, with an optimal dosage around 0.10% by binder weight. However, higher contents reduce flowability due to agglomeration, and further research is needed to address these limitations and maximize benefits [2], [3]. Investigated CNTs (0–0.075 wt%) and steel fibres in rigid pavement concrete. Found optimal CNT dosage improves compressive, tensile, and flexural strengths while reducing costs. Steel fibres further enhanced mechanical properties [8]. Studied self-compacting lightweight concrete with CNTs (0–0.06 wt%) and steel microfibers (0–1 vol%). CNTs and fibres together increased compressive strength by up to 64% and tensile strength by 36%, reduced porosity, and improved durability by filling pores and promoting hydration [9]. Analyzed UHPFRC with varying steel fiber content/aspect ratios. A higher fibre content enhanced compressive strength and modulus of elasticity, but the benefits diminished beyond 2 vol%, resulting in reduced workability. Developed prediction models validated with extensive test data [10]. Steel fibre-reinforced concrete enhances post-cracking, flexural, and tensile strength through the fibre bridging effect, albeit at the expense of reduced workability. Performance depends on fibre geometry, content, orientation, and distribution, with perpendicular orientation to cracks most effective. Further research is needed to control fibre alignment for enhanced mechanical and structural properties [1]. This study investigates HP-SFRC with 10–15% silica fume and steel fibres (0–1.5% Vf, aspect ratios of 80 & 53) at a w/b ratio of 0.30–0.40. Results show moderate compressive and significant flexural strength gains, especially at Vf = 1.5% with 15% silica fume. Predictive models using empirical equations, ANFIS, and MLR demonstrated high accuracy against experimental and published data [1], [5].

A. Carbon Nanotube (CNTs)

A carbon nanotube (CNT) is a tube made of carbon with a diameter in the nanometre range (nanoscale). They are one of the allotropes of carbon. Two broad classes of carbon nanotubes are recognised [13].

- **Single-Walled Carbon Nanotubes (SWCNTs)** have diameters around 0.5–2.0 nanometres, about 100,000 times smaller than the width of a human hair. They can be idealised as cut-outs from a two-dimensional graphene sheet rolled up to form a hollow cylinder [9], [13].
- **Multi-Walled Carbon Nanotubes (MWCNTs)** consist of nested single-wall carbon nanotubes in a nested, tube-in-tube structure. Double- and triple-walled carbon nanotubes are exceptional cases of MWCNT [13].



[Fig.1: SWCNTs And MWCNTs]

Carbon nanotubes exhibit remarkable properties, such as exceptional tensile strength and thermal conductivity, due to their nanostructure and the strength of the bonds between carbon atoms. Some SWCNT structures exhibit high electrical conductivity, while others behave as semiconductors. In addition, carbon nanotubes can be chemically modified. These properties are expected to be valuable in various areas of technology, including electronics, optics, composite materials (which can replace or complement carbon fibres), nanotechnology (encompassing nanomedicine), and other applications of materials science. Due to their exceptional tensile strength, electrical conductivity, and Nano-scale structure, they are particularly effective in modifying concrete's microstructure. When properly dispersed, CNTs enhance mechanical performance, reduce microcracks, and improve the durability of materials. Key properties of multi-walled CNTs include high purity (95%), nanoscale diameter (20–30 nm), and high surface area (90–350 m²/g) [7].

[Fig.2: Carbon Nanotubes (CNTs)]

B. Steel Fibre (SFs)

Steel fibres are short, discrete strands of steel added to concrete as a form of micro-reinforcement. They typically range in diameter from 0.25 to 1 mm and in length from 10 to 60 mm. They are randomly dispersed throughout the concrete mix [6], [10]. Their primary purpose is to enhance the tensile strength, toughness, and crack resistance of the concrete, particularly under dynamic or impact loads [1]. Steel fibres can be made from carbon steel, stainless steel, or recycled materials, and they come in various shapes, including hooked, crimped, straight, or corrugated. When distributed adequately in concrete, these fibres bridge microcracks, delay crack propagation, and improve post-cracking ductility [10], [11], [12].

[Fig.3: Steel Fibre (SF)]

C. Artificial Sand (AS)

Artificial Sand (AS), also known as Manufactured Sand

(M-sand), is a fine aggregate produced by mechanically crushing hard stones, such as granite, basalt, or quartzite. It is used as a replacement for natural river sand in concrete and construction applications due to increasing scarcity, environmental regulations, and the high cost of natural sand.

[Fig.4: Artificial Sand (AS)]

D. Objective of Carbon Nanotubes and Steel Fibre in Concrete

- Enhance compressive strength using CNTs due to their high surface area and aspect ratio.
- Improve flexural and tensile strength through the crack-bridging action of steel fibres.
- Increase ductility and toughness by combining CNTs and SFs for better energy absorption.
- Reduce microcracks and macrocracks, enhancing crack resistance.
- Improve durability by minimizing shrinkage cracks and increasing resistance to corrosion and thermal stresses.

II. LITERATURE REVIEW

There have been various experimental and theoretical investigations performed on the topic of Carbon nanotubes and steel fibres. Some of the experimental studies conducted in this field are presented in the following literature review.

M.S. Khan, A. Fuzail Hashmi, M. Shariq, S.M. Ibrahim (2023) [1]. For a decade, attempts have been made to induce ductility into concrete; fibre-reinforced concrete is one such attempt. Adding fibres to concrete enhances the material's post-cracking strength due to the bridging effect of the fibres. In tunnelling, fibres are preferred over reinforcement because they provide all-around reinforcement for the concrete and lessen the risk of concrete spalling. Different types of fibres exist, such as steel, glass, polypropylene, and others. However, more research is conducted on steel fibre-reinforced concrete among the mentioned fibres. Steel fibre has various effects on the strength and properties of concrete. Several factors, including fibre geometry, fibre content, fibre orientation, and fibre distribution, influence the impact of steel fibres on the mechanical properties of fibre-reinforced concrete. Adding fibres reduces the workability of concrete but increases its hardening properties. Fibres enhanced the compressive strength of concrete marginally up to the optimal fibre content. Nevertheless, the flexure and splitting tensile strength increased linearly with increased fibre content. Some researchers noted that fibres oriented perpendicular to the crack arrest the crack more effectively than those oriented parallel to the crack. The literature evaluation suggests that further experimental and analytical research is needed to develop a technique that controls the orientation and distribution of fibres in concrete. Future research directions are also highlighted in this article for improving the mechanical and structural characteristics of concrete using fibre-reinforced concrete.

MohamedSamir Eisa a, Ahmed Mohamady b, MohamedE. Basiouny a Ayman Abdulhamid a, Jong R. Kim (2023) [2]. Three different percentages of carbon nanotubes (CNTs) (0.1%, 0.5%, and 1% by mass of asphalt cement) were used to modify conventional asphalt cement (60/70) in this study. The mechanical properties of the modified asphalt cement and mixture were evaluated. Penetration grade, kinematic viscosity, softening point and dynamic shear rheometer test were measured to evaluate physical properties of modified asphalt cement. The results exhibited that modifying asphalt cement with CNTs decreased its penetration and increased its kinematic viscosity and softening point. Rutting parameter increased with CNTs at the given temperature for both unaged and RTFOT-aged samples. Marshall stability tests, low-temperature cracking tests, indirect tensile tests, and wheel tracking tests were conducted to assess the mechanical performance of the modified hot asphalt mixture. The Marshall stability increased with the addition of CNTs, but there was no significant difference at 0.5 and 1.0 wt%. In contrast, the Marshall flow decreased with the addition of CNTs. The results of the wheel tracking test showed that the rut depth decreased by 45% upon adding 0.5% CNTs by weight of asphalt cement; also, this percentage of CNTs provided an improvement in low-temperature cracking and indirect tensile strength of the asphalt concrete. This study highlights that incorporating CNTs into asphalt cement improves the performance of asphalt concrete pavement in both hot and cold weather, thereby prolonging the pavement's service life and reducing maintenance expenses.

Jawad Ahmad a, Zhiguang Zhou (2023) [3]. The addition of carbon nanotubes (CNTs) to concrete has the potential to enhance the strength, durability, and thermal properties of the concrete, resulting in more durable concrete. However, further study is required to understand the benefits and limitations of CNT-based concrete fully. Therefore, this article aims to conduct a rigorous evaluation of CNT-based concrete and to highlight the need for further research to enhance its mechanical and durability properties. All the crucial aspects of CNT, including its types, structure, preparation, and physical and chemical properties, are reviewed. Additionally, the flowability, durability, high-temperature performance, and morphology of CNT-based concrete are also examined. Results show that the CNT increased the concrete strength and durability. Additionally, with the inclusion of CNT, the performance of concrete at high temperatures improved. However, the addition of CNT caused a decline in concrete flowability due to agglomeration, particularly at higher doses. Most studies recommend a dosage of 0.10% (by weight of binder)

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as the ideal CNT dosage. The study also identifies the research gaps that need to be addressed to enhance the performance of CNT-based concrete further.

Peng Zhang, Jia Su, Jinjun Guo, Shaowei Hu (2023) [4]. Carbon nanotubes (CNTs) have been increasingly used in concrete due to their good mechanical properties and electrical conductivity. Scholars worldwide have conducted in-depth research on carbon nanotube concrete (CNTC). Notably, they have demonstrated that CNTs can play a variety of roles in concrete, including bridging matrix cracks, filling internal pores, and promoting the cement hydration reaction. Based on these studies, the different dispersion modes of CNTs are compared, and the workability of CNTC is analysed in this paper. At the same time, the mechanical properties of CNTC, including compressive strength, tensile strength, flexural strength, and dynamic performance against impact, are systematically reviewed. The durability of CNTC is also reviewed, including chloride penetration resistance, carbonation resistance, sulfate resistance, impermeability, high-temperature resistance, and freezing-thawing resistance. In addition, the application of CNTs as a conductive filler in concrete, as well as the analysis of the microscopic mechanism of CNTs, is also summarised. The results show that the addition of CNTs generally reduces the workability of concrete; however, the pre-dispersed liquid CNTs relatively increase the liquidity. CNTs with OH groups and nickel have an outstanding enhancement in mechanical properties. COOH-functionalized and shorter CNTs significantly improve the dynamic impact resistance of ultra-high-performance concrete. CNTs optimize internal pore structure and enhance interface transition zone (ITZ) to improve durability. At the same time, CNTC also exhibits good quality maintenance at high temperatures, and its internal structure transforms into a new form at 600 ℃. As self-sensing concrete, CNTC exhibits good strain sensitivity and can be utilised to detect structural defects. Generally, CNTC is a new building material with promising application prospects. The review aims to help scholars systematically understand the action behaviour of CNTs in concrete terms and may further promote the application of CNTC in practical projects.

P. Ramadoss, a, L. Li b, S. Fatima c, M. Sofi d (2023) [5]. This paper presents the outcome of the investigation of high-performance steel fibre reinforced concrete (HP-SFRC) with a water-to-binder ratio (w: b) of 0.30- 0.40. The binder included cement replacement of 10% and 15% by silica fume. Fibre volume fractions (Vf) of 0, 0.5, 1.0 and 1.5% with aspect ratios of 80 and 53 were used. The study aims to present the effect of incorporating micro-silica and steel fibres on the mechanical performance of HP-SFRC. Experimental results show that a moderate increase in compressive strength and significant improvement in flexural strength of HP-SFRC at Vf = 1.5% (reinforcing index = 3.88) with 15% micro-silica replacement. Empirical expressions were developed for compressive and flexural strength of HP-SFRC as a function of steel fibre volume fraction. The power relation between flexural tensile and compressive strengths was created with an integral absolute error of 6.39. Further, the validity of the proposed models was tested against published data. A machine learning framework was established based on an adaptive neuro-fuzzy inference system (ANFIS) to predict the compressive strength of HP-SFRC mixes with higher accuracy. Finally, a multiple linear regression (MLR) model is proposed for the strength of HP-SFRC mixes and tested against published data. The validity of the MLR model is verified through experimental results, demonstrating its good predictive capability.

Guohua Xing a, Yangchen Xu a, Jiao Huang a, Yongjian Lu a, Pengyong Miao a, Pattharaphon Chindasiriphan b, Pitcha Jongvivatsakul b, Kaize Ma a (2023) [6]. Introducing steel fibres (SFs) into carbon nanotube (CNT)-reinforced concrete can fully exert the synergistic effect of SFs and CNTs at both micro and macro levels, alleviating the high brittleness of CNT-reinforced concrete while enhancing its mechanical properties. In this study, the mechanical behaviour of CNT concrete reinforced with hooked-end steel fibre (HSF) and milled steel fibre (MSF) with respective volume fractions of 1.0%, 1.5%, and 2.0% was examined regarding compressive (cubic and axial), splitting tensile, and flexural strengths at 28 days. Meanwhile, Digital Image Correlation (DIC) was used to quantify the crack propagation on the specimen surface under varied flexural loads. The results confirmed the ability of CNTs to improve the compressive, splitting tensile, and flexural strength of plain concrete, but they also revealed an inability to refine brittle failure. Including SFs further enhanced the strength and reduced the brittleness of CNTs concrete. In terms of fibre type, HSF-reinforced CNT concrete outperformed MSF-reinforced concrete in compressive and splitting tensile strength, while reducing the brittleness of CNT concrete; however, it surrendered the latter in flexural strength. Crack propagation observed by DIC demonstrated the good ductility of the reinforced specimens, due to the ability of SFs to restrict crack propagation and enhance the deformation of the entire specimen. Additionally, Scanning Electron Microscope (SEM) observation of the CNTs-compacted concrete microstructure revealed an excellent synergistic effect of CNTs and SFs in bonding with the cement matrix. Macroscopically, CNTs and SFs can together improve the mechanical properties and ductility of cement materials, as well as their structural durability.

Luciano Feo a, Annavirginia Lambiase a, Enzo Martinelli a, Rosa Penna a, Marco Pepe b (2023) [7]. The addition of carbon nanotubes is an effective method for enhancing the mechanical properties and durability performance of structural concrete. Recently, experimental studies have investigated the behaviour of Ultra-High-Performance Fibre Reinforced Concrete (UHPFRC) mixtures, including steel fibres and carbon nanotubes, duly dispersed within their matrix. This paper presents the numerical results of a preliminary analysis on the effect of carbon nanofillers on the stress-strain behaviour of the cementitious matrix, as well as on the bond interaction between the matrix and the steel fibres that constitute UHPFRC. For this purpose, the meso-mechanical model developed by two of the authors for studying the post-cracking response of fibre-reinforced concrete is here extended and applied to evaluate the effects of adding nanofiller on the cracking and post-cracking response of

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UHPFRC specimens. To characterise the stress-strain relationships of the cementitious matrix and to back-calculate the bond-slip laws of steel fibres embedded within it, a comparison with experimental results available in the literature has also been developed.

Abeer Hassan, Sameh Galal, Ahmed Hassan, & Amany Salman (2022) [8]. Rigid pavements have become a growing demand in recent years, as they require less maintenance and renovation compared to other types of pavements. However, traditional rigid pavement faces various challenges and difficulties over its lifetime. It has a significantly higher initial erection cost than asphalt pavements, greater sensitivity to dynamic stresses, and is highly susceptible to temperature variations, which can cause cracking. Previous works have addressed these drawbacks by utilising effective materials as alternatives to cement and/or aggregates in pavement mixtures. In the last few years, considerable interest has been shown in nanomaterial applications to enhance the mechanical performance of construction materials, which can also be utilised for rigid pavement constructions. This improvement is attributed to the role of nanomaterials in concrete as nano-reinforcements and nanofillers. On the other hand, various types of fibres have been used to improve the performance of concrete constructions. This study examines the impact of incorporating carbon nanotubes (CNTs) and steel fibres (SFs) into concrete mixtures. A series of experiments on concrete mixes with varying weight percentages of CNTs (0%, 0.025%, 0.050%, and 0.075%) was conducted to determine the optimal cost and amount of CNTs to add to a concrete mix. Compressive, tensile, and flexural strength characteristics are investigated. In the second experimental stage of this work, the effect of adding steel fibres to the mixture was studied.

Y. Mohammadi*a, M. Bagheripour Asilb (2022) [9]. In this research, the engineering characteristics of self-compacting lightweight concrete (SCLWC) containing carbon nanotubes and steel micro-fibres were evaluated. The variables included the amount of carbon nanotubes (0, 0.02, 0.04, and 0.06% by weight of cement) and steel micro-fibre (0, 0.5, and 1% by volume). Lightweight expanded clay aggregate was used as a lightweight aggregate. The experimental tests included self-compacting tests, as well as compressive, splitting tensile, and flexural strengths, along with ultrasonic pulse velocity, electrical resistivity, water penetration depth, and scanning electron microscopy. Adding 0.02 to 0.06 per cent of carbon nanotubes to SCLWC reinforced with steel microfibers increases the compressive strength by about 33 to 64 per cent. The use of 0.06% carbon nanotubes and 1% steel microfiber increased the splitting tensile strength by 36%. The use of carbon nanotubes and steel micro-fibres has the effect of influencing the filling of empty spaces and reducing concrete porosity. This can be attributed to the growing process of cement paste hydration and the filling of pores and capillary pores with the products of cement reactions, resulting in concrete compaction. Adding 0.02% carbon nanotubes to SCLWC samples containing 0.5% and 1% steel microfibers increased the 28-day compressive strength by 36%, 34%, and 33%, respectively.

Jian Yang a b, Baochun Chen b c, Camillo Nuti d (2021) [10]. The compressive properties (including compressive strength and modulus of elasticity) of ultra-high-performance fibre-reinforced concrete (UHPFRC) are the most critical performance indices in structural design. This paper presents experimental results from tests conducted on 36 UHPFRCs with varying volume fractions and aspect ratios of steel fibre to investigate the effect of steel fibre on the compressive properties of UHPFRC. The test results indicated that the compressive strength and modulus of elasticity of the hardened UHPFRC increase as the fibre volume fraction or aspect ratio increases. However, the increasing trend of compressive strength and modulus of elasticity slowed down when the volume fraction exceeded 2%. It was observed that the steel fibre can restrain the occurrence and development of cracks when UHPFRC specimens are compressed, providing a positive effect for reinforcing UHPFRC. However, it also reduces the flowability of fresh UHPFRC, which is negative for the reinforcing effect. X-ray CT scanning revealed that the porosity and pore size of hardened UHPFRC increased with the increase in the fibre volume fraction, due to its weakened flowability. A prediction model was established based on the analysis of the positive and negative effects of the steel fibre. Semi-empirical prediction formulas for the compressive strength and modulus of elasticity were proposed in this paper through regression analysis of test data, which were subsequently verified and revised using an experimental database of 155 tests from the literature. Additionally, a relationship formula between the modulus of elasticity and the compressive strength of UHPFRC was presented, verified, and refined using an experimental database comprising 320 tests conducted worldwide.

Qinyuan Zhang, Wenwen Xu, Yichen Sun, Yongcheng Ji (2021) [11]. This paper investigated the degradation of microscopic and mechanical properties of axially compressed concrete with varying steel fibre content under chemical erosion and freeze-thaw environments. Concrete cylinders with three types of steel fiber contents (0%, 1%, 2%) were selected to study the durability behavior concerning different environmental effects up to 28 days, which included tap water, 3.5% sodium chloride solution, 10% sodium sulfate solution, 5% sulfuric acid solution, 2 mol/L sodium hydroxide solution, and 100 freeze-thaw cycles. The variation in specimens' microstructure and axial bearing capacity with different fibre contents was studied as the chemical erosion cycle increased, and the mass and pH variations of the specimens were measured. According to the law of micro-cracks, the deterioration degree was assessed, and a numerical analysis model was established to quantify the reliability of the structure with varying fibre content. The results show that the addition of steel fibre can effectively improve the axial bearing capacity of concrete; however, a freeze-thaw environment and chemical erosion can accelerate the failure of fibre-reinforced concrete. The optimal content of steel fibre was determined to be 1% for sodium chloride and sodium sulfate environments, and 2% for freeze-thaw cycle, dilute sulfuric acid, and sodium hydroxide environments. The finite element software Abaqus was used to simulate and analyze the freeze-thaw cycle and mechanical test of concrete, which verified the rationality

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of the test results. The research results will provide a theoretical basis for predicting the performance deterioration of steel fibre-reinforced concrete under various erosion conditions and periods.

Jegatheeswaran Dhanapal, Sridhar Jeyaprakash (2019) [12]. The paper aims to analyse and study the features of steel fibre-reinforced concrete (SFRC) and plain concrete that contain combined fibres of various aspect ratios. Experiments on works are held to examine the features of the new combination of concretes. Simultaneously, the characteristics of the hardened concretes are investigated by performing tests on compression, flexural strength, and split tensile strength (STS). It further verifies the effects of fibres when they are distributed in the hinged zone of structural components to obtain financial benefits by minimising the amount of steel fibre in the concrete mix. The results show that the combined reinforced concrete steel fibre can be employed as a better combination for SFRC, achieving strength in STS and flexure. Nevertheless, an enhanced ability to work was achieved by incorporating more microfibers into the concrete. There is a slight variation in the features of concrete between beams with full-length fibres and those with fibres available in the hinged zone. Similarly, the categorization of neural networks, such as Neural Network–Levenberg–Marquardt (NN-LM) and Neural Network-Gradient Descent (NN-GD), is further used to perform the experimentation in an intelligent manner, which comes close to the actual values while calculating the mean absolute error (MAE) and root mean square error (RMSE) values.

Vidivelli B, Ashwini B (2018) [13]. This paper reviews the literature on Carbon Nanotube (CNT) integration, ranging from 0.15% to 2.5%, in terms of its effect on the strength characteristics and durability of concrete. The sonication process is carried out by adding CNTs with surfactants by weight to the cement or water. It is obtained from various literature sources, which explain that ultrasonic dispersion techniques were adopted to disperse them uniformly. Tensile, compressive strength, durability, and bending tests have been conducted on the specimens in the past experimental program. This paper presents the methodologies and results of various research papers on similar experiments. Moreover, this paper discusses how to enhance the properties mentioned above.

III. METHODOLOGY

The experimental investigation was conducted to evaluate the mechanical properties of high-performance concrete reinforced with Carbon Nanotubes (CNTs), Steel Fibres (SFs), and 100% Artificial Sand (AS) as fine aggregate. The methodology involved the following steps:

A. Specimen Types

- Cubes: 150 mm × 150 mm × 150 mm (Compressive Strength Test)
- Cylinders: 150 mm × 300 mm (Split Tensile Strength Test)
- Beams: 150 mm × 150 mm × 700 mm (Flexural Strength Test)

B. Material Proportions

- Artificial Sand (AS)**:** Used as a 100% replacement for natural river sand.
- Carbon Nanotubes (CNTs)**:** Added at 1%, 2%, and 3% by weight of cement.
- Steel Fibres (SFs)**:** Constant dosage of 5% by volume of coarse aggregates.

C. Mixing and Dispersion

- CNTs were dispersed using ultrasonic sonication with surfactant to ensure uniform distribution.
- All materials were mixed using a mechanical mixer to ensure homogeneity.

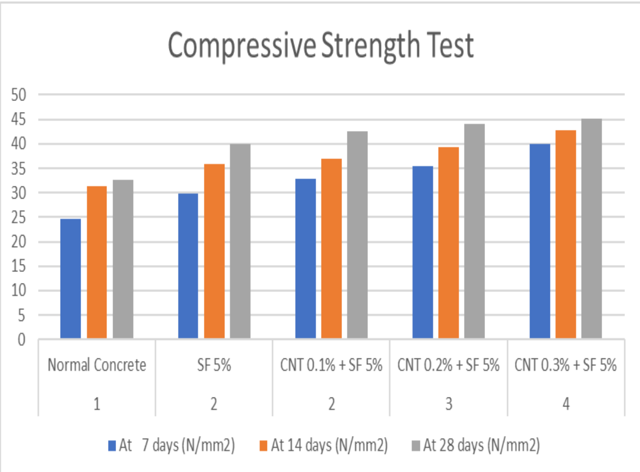
D. Curing and Testing

- All specimens were cured for 7,14 & 28 days.
- Mechanical tests included Compressive Strength, Split Tensile Strength, and Flexural Strength

IV. RESULT AND DISCUSSION

A. Compressive Strength

Compressive strength is a critical parameter for evaluating the performance and structural integrity of concrete under various loading and environmental conditions. In this investigation, M30 grade concrete incorporating 100% artificial sand (AS) and 53-grade cement was used. cube specimens (150 mm × 150 mm × 150 mm) were tested to assess compressive strength at 7, 14, and 28 days for different combinations with Carbon Nanotubes (CNTs), Steel Fibres (SFs), and 100% Artificial Sand (AS). Compressive strength tests were conducted using a universal testing machine under standard loading conditions. The results demonstrate a clear enhancement in strength due to the inclusion of steel fibres and carbon nanotubes:



[Fig.5: Graph Showing Compressive Strength Of The Specimens]

B. Flexural Strength

Flexural strength is the ability of the material to withstand bending forces applied perpendicular to its longitudinal axis. It is also known as modulus of rupture, or bend strength, or transverse rupture strength. It is a material property, defined as the stress in a material just before it yields in a flexure test. In this experiment, we

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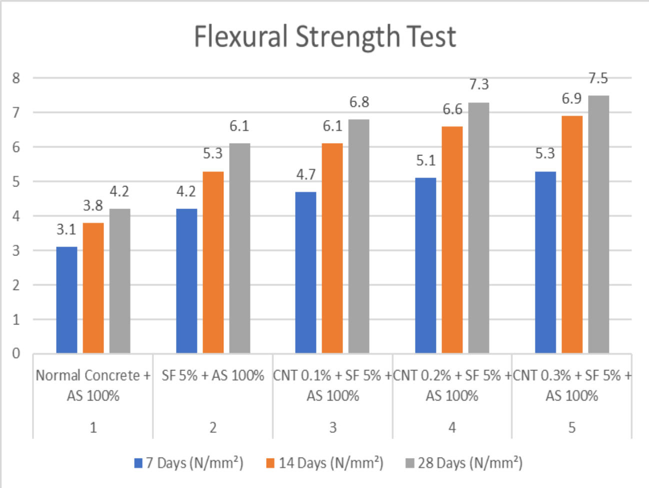
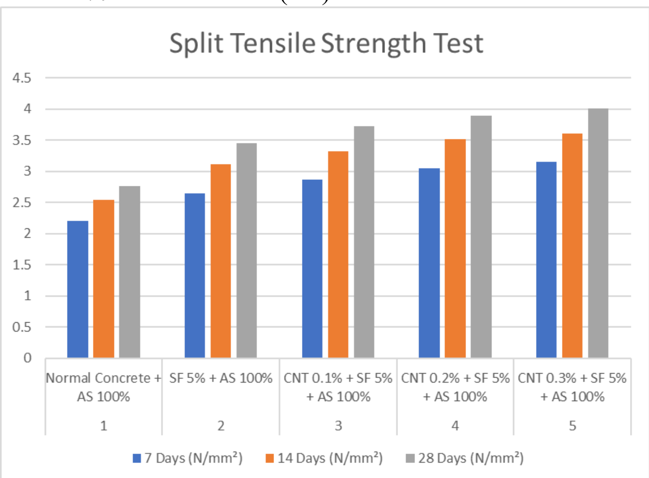
used M30-grade concrete with 53-grade cement. For the test of flexural strength, we took beams with different amounts of Carbon Nanotubes (CNTs), Steel Fibres (SFs), and 100% Artificial Sand (AS).



[Fig.6: Graph Showing Flexural Strength of The Specimens]

C. Splitting Tensile Strength

The splitting tensile strength test was conducted by applying a diametrical compressive load along the length of cylindrical specimens until failure. This loading induces tensile stresses across the vertical plane and compressive stresses in the surrounding regions. In this study, M30-grade concrete was used with 53-grade cement. A total of 24 cylindrical specimens (150 mm × 300 mm) incorporating varying dosages of Carbon Nanotubes (CNTs), Steel Fibres (SFs), and 100% Artificial Sand (AS) were tested.



[Fig.7: Graph Showing Splitting Tensile Strength of The Specimens]

V. CONCLUSION

This study evaluated the mechanical performance of high-strength concrete made with 100% artificial sand (AS), reinforced with 5% steel fibres (SF), and varying dosages of carbon nanotubes (CNTs) ranging from 0.1% to 0.3%. The concrete mixes were tested for compressive strength, flexural strength, and split tensile strength at 7, 14, and 28 days.

The experimental results confirmed that the inclusion of steel fibres significantly enhanced all three mechanical properties compared to the control mix made with artificial sand alone. The addition of CNTs further improved performance, demonstrating a strong synergistic effect with SF.

- Compressive Strength: Increased from 32.52 N/mm² (control) to 44.61 N/mm² with 0.3% CNT and 5% SF, a total improvement of 37%.
- Flexural Strength: Improved from 4.2 N/mm² to 7.5 N/mm², indicating a 78% increase due to the combined reinforcement.
- Split Tensile Strength: Increased from 2.76 N/mm² to 4.01 N/mm², marking a 45% enhancement in tensile resistance.

The results also revealed that while strength gains continued with increasing CNT content, the rate of improvement diminished beyond 0.2% CNT. This suggests that a 0.2% CNT + 5% SF combination may be the most efficient in terms of both cost and performance.

Overall, the study concludes that the hybrid reinforcement of steel fibres and carbon nanotubes effectively enhances the mechanical performance of concrete made with 100% artificial sand. The multi-scale reinforcement mechanism—combining macro-scale crack bridging by steel fibres and nano-scale densification by CNTs—offers a promising approach for developing high-performance concrete with sustainable alternatives to natural sand.

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After aggregating input from all authors, I must verify the accuracy of the following information as the article's author.

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