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EXPERIMENTAL STUDY ON NANO TIO₂ CONCRETE REINFORCED WITH POLYPROPYLENE FIBER

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ABSTRACT

Over the decades, researchers have attempted to include extra cementitious elements into concrete in order to boost its strength and longevity. Recent advancements in the field of nano-engineered concrete have demonstrated that nanomaterials significantly improve the mechanical and durability properties of concrete. In this study, the properties of concrete are investigated by substituting different percentages of Nano TiO_2 particles for cement 0%, 1%, 2%, 3%, 4%, and 5%, and by using 0.5% of the volume of the concrete's reinforcing to be made of polypropylene fiber. In addition to the microstructural study, the results of the compressive, split, flexural, and slump tests were compared for a variety of percentages. By combining 0.5% polypropylene fiber with 2% nano-TiO_2, concrete specimens' mechanical strength can be successfully enhanced. After 28 days, the concrete shows increase in its compressive strength of 4.89%, splitting tensile strength of 15.32%, and flexural strength of 14.69%.

Keywords: Compressive Strength, Flexural strength, Nano Materials, Flowability, Water Absorption.

1. INTRODUCTION

Concrete is frequently utilized in construction, including houses, dams, and transportation infrastructure. The brittle nature of conventional concrete materials (CCMs) makes them prone to the uncontrolled growth of cracks and their limited-service life. Global economic growth has led to increased investments in urban and infrastructural developments. The excessive use of raw materials and concrete has resulted in a short-term shortage of non-renewable natural aggregates, as well as significant construction waste and greenhouse gas emissions. This has a negative impact on environmental protection and does not align with the concept of low-carbon, green, and sustainable development [1, 2, 8]. As a result, it is desperately necessary to find new materials to replace the consumption of these commodities. Manufactured sand and recycled aggregate have steadily emerged as viable alternatives and are now major components of the green development of engineering materials in many nations. Concrete nanotechnology involves the use of nanoscale remodelling techniques to create a new, suitable generation of cementitious composites with appropriate physical behaviour, which helps to create the special qualities of concrete. The ultimate objective of concrete nanotechnology is to study concrete at the nanoscale and to examine the nanoparticles that are used to provide concrete superior qualities. The introduction of nano-cement and nano-cementing elements into concrete has resulted in several technological advancements, including increased strength, ductility, crack resistance, and a reduction in curing time. The majority of sectors now use nano cement as a result of these beneficial developments. Carbon nanotubes, carbon nanofibers, nano-TiO_2, nano-Al_2O_3, nano-ZnO_2, nano-$CaCO_3$, SiO_2, and other nanoparticles can alter the mechanical and physical characteristics of cement concrete. One reason cement concrete has a poor strength is that when the cement particles combine, the resulting mixture is made up of holes ranging in size from micrometers to millimetres [2-6]. The use of nanotechnology has provided a solution to this issue. Nanoparticles can fill holes and pores in concrete microstructures, resulting in denser materials compared to CCMs. The filling actions of nanoparticles restrict crack formation and initiation at very early times and stop crack propagation. Nanoparticles in concrete improve binding strength and integrity between cement paste and aggregates. Incorporating nanoparticles can quickly produce more calcium silicate hydrate (C-S-H) gels, improving the microstructure of concrete materials. Concrete's internal pores can be effectively filled with nano-titanium dioxide (nano-TiO_2), a photocatalyst [5-7, 14, 21,22]. It has the ability to effectively fill the pores in cement paste that has solidified as well as correct surface imperfections on recycled aggregate. It also has a special effect on enhancing concrete's performance. The use of mineral additives, either traditional or nanosized, in concrete has been shown to increase its strength globally, but numerous researchers have also noted that as concrete's strength increases, so does its brittleness [8-10]. The researchers cited inadequate binding and low tensile strength as the causes of this brittleness. Fibers can be added to concrete to aid with the problem of reduced tensile strength. It is widely known that fibers increase the energy absorption capacity of concrete, making it more ductile and resistant to fatigue and impact loads. Furthermore, using fibers increases the cementitious materials' toughness, flexural strength, and shear strength as well as their resistance to shrinkage, cracking, and permeability, all of which contribute to improved fatigue and impact resistance. There are numerous papers available for fibers like polymer, carbon, and steel from the numerous research projects that used fibers in concrete [11,12].

The impact resistance of concrete containing silica fume and polypropylene fiber, added in 0.2%, 0.3%, and 0.5% amounts, was reported by the author. According to the authors, adding 0.5% of fiber increased the impact resistance [13]. This study used silica fume as an additional cementitious material in a high-strength concrete mix, conducting experimental investigations with various fibers and combinations. The authors employed 0.85% steel and 0.15% polypropylene fibers at a total fiber volume fraction of 1% by volume of concrete, as well as steel and polypropylene fibers separately. It was stated that the combined use of polypropylene and steel performed better than each substance utilized alone [14].

In this study, the properties of concrete are examined with the use of Nano TiO_2 particles at varying percentages (0–5%) in place of cement and 0.5% polypropylene fiber utilized by volume as reinforcement in the concrete. The slump test for fresh concrete qualities was measured and the findings were given. Concrete specimens (cubes, cylinders, and beams) were cast, and the effects of adding 0%, 1%, 2%, 3%, 4%, and 5% nano TiO_2 to cement by weight of cement were tested for 7, 14, and 28 days. Compressive, split, and flexural strength test results were compared for a range of percentages. In this study different concrete mix design of 0%, 1%, 2%, 3%, 4%, and 5% nano TiO_2 with 0.5% polypropylene fiber represented by 0.5PC0, 0.5PC1, 0.5PC2, 0.5PC3, 0.5PC4 and 0.5PC5 respectively.

2. MATERIALS AND METHODOLOGY

MATERIALS

1. CEMENT

According to IS 4031:1996 part-1 recommendations, Ordinary Portland Cement (OPC) of grade 43 was utilized in this study. The specific gravity (SG), fineness, initial setting time (IST), final setting time (FST) and consistency limit of the cement were tested [15,16].; the results are displayed in Table 1 below.

Table 1: Cement test results data

TESTS	RESULTS
CONSISTENCY	29.5%
SG	3.02
IST	48 min
FST	412 min
Fineness	5.8%

2. FINE AGGREGATE

A fine aggregate with a specific gravity of 2.68, Zone II, 8% silt content, water absorption 0.95% and a fineness modulus of 3.12 was utilized to construct the concrete mix utilizing natural river sand as per IS 383:2016 [17,18].

3. COARSE AGGREGATE

The coarse aggregate used in the concrete mix has a specific gravity of 2.77, water absorption of 0.4%, and aggregate sizes of 20 mm and 10 mm with a ratio of 60:40, according to IS code 383:2016 [17,18].

4. WATER AND SUPER PLASTICIZER

This study used the Fosroc Conplast SP 430 superplasticizer as an admixture, which has a specific gravity of 1.415. Clean portable water used in this study for mixing of concrete ingredients.

5. NANO TiO_2 AND POLYPROPYLENE FIBER

Table 2 below lists the parameters of the TiO_2 nano material and polypropylene fiber that was used to prepare the concrete mix. Fig 1. displays the nanoparticles of TiO_2. Polypropylene fiber used in this study provided by Kalyani private limited from India Mart depicted in Fig 2. and nano TiO_2 was provided by the Aps marketing from India Mart.

Table 2: Nano TiO_2 and Polypropylene fiber test results data

Material	Properties	Value
Nano TiO_2	Particle Size	40-400 nm
	Purity	96%
	Structure	Ructile
	PH value	6.7
Polypropylene fiber	Length	12 mm
	Width	0.5-1mm

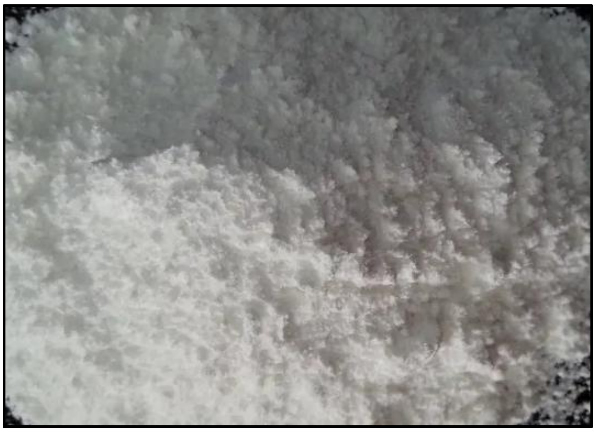

Figure 1. Nano TiO_2 used in mix design

Figure 2. Polypropylene fiber for mix design

MIX PROPORTION

IS 10262:2019 was used in the mix design process. Concrete cubes (150mm x 150mm), cylinders (100mm x 200mm), and beams (150mm x 150mm x 700mm) were cast and cured in a tank for 7, 14, and 28 days, achieving a characteristics compressive strength of 35 N/mm^2 (M35) [19]. Water cement ratio 0.375 used in this study. Compressive strength, flexural strength, split tensile strength along with slump and microstructural study test were performed on concrete specimens. The mix proportion used in this study shown in Table 3.

Table 3: Mix proportion used in this study

Materials	Quantities (kg/m^3)
Cement	420.61
Fine aggregate	169.51
Coarse aggregate	646.40
Water	1192.43
Water Cement ratio	0.375
Polypropylene fiber	0.5% volume of concrete
Nano TiO_2	Varying from 0% to 5%

3. RESULTS AND DISCUSSIONS

- **FLOWABILITY**

Concrete's workability is impacted by nano TiO_2. Adding nanoparticles generally thickens and stiffens a mixture, which may affect how easily it can be handled and applied. The high specific surface area of the Nano particles will absorb more water if too much TiO_2 is added, causing continuous pockets to form within the paste matrix and increasing the mixture's porosity as depicted in Fig 3. To ensure proper workability, modifications were made to the mix design, including the quantity of water and super plasticizers. Concrete becomes less workable as the percentage of TiO_2 Nanoparticles rises; therefore, plasticizers are added to the mixture to keep it intact. As increment in nano TiO_2 in concrete mix the value of slump starts decreasing from 1% to 5% as shown in Table 4.

Table 4: Slump value used in this study

Mix Code	Slump (mm)
0.5PT0	112
0.5PT1	108
0.5PT2	102
0.5PT3	98
0.5PT4	92
0.5PT5	84

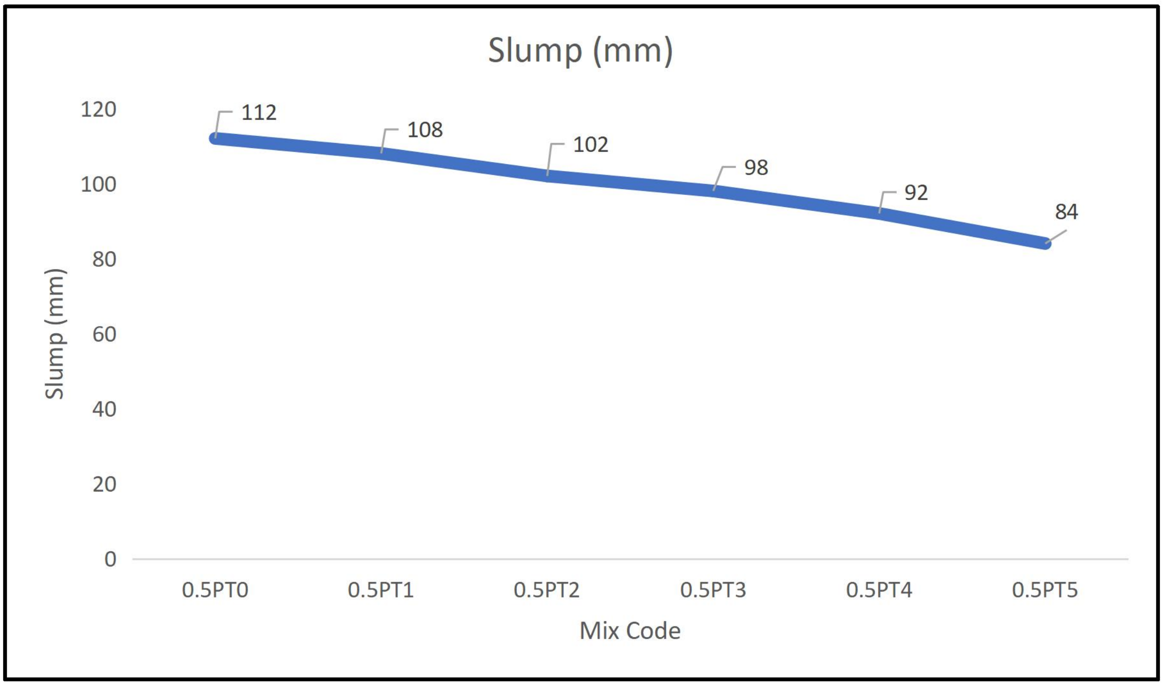

Figure 3. Slump data for different concrete mix

- **COMPRESSIVE STRENGTH**

When the 150 mm x 150 mm cubes for the compressive strength test had cured, they were put under the UTM machine and loaded at pace rate 5.25 KN/sec up to until the maximum load was reached [20]. At that point, the needle went back to its starting position and the cubes were tested for failure. Generally, the average of three cubes will be used to calculate the compressive strength. The characteristics indicated below are shown by the compressive test results, as summarized in Table 5.

Table 5: Compressive strength value determines through experimental study

Mix Code	Compressive Strength		
	7 days	14 days	28 days
0.5PT0	26.9	32.9	43.18
0.5PT1	27.2	33.6	44.78
0.5PT2	28.2	34.8	45.29
0.5PT3	27.5	33.8	44.85
0.5PT4	27.1	33.2	43.78
0.5PT5	25.9	31.5	42.9

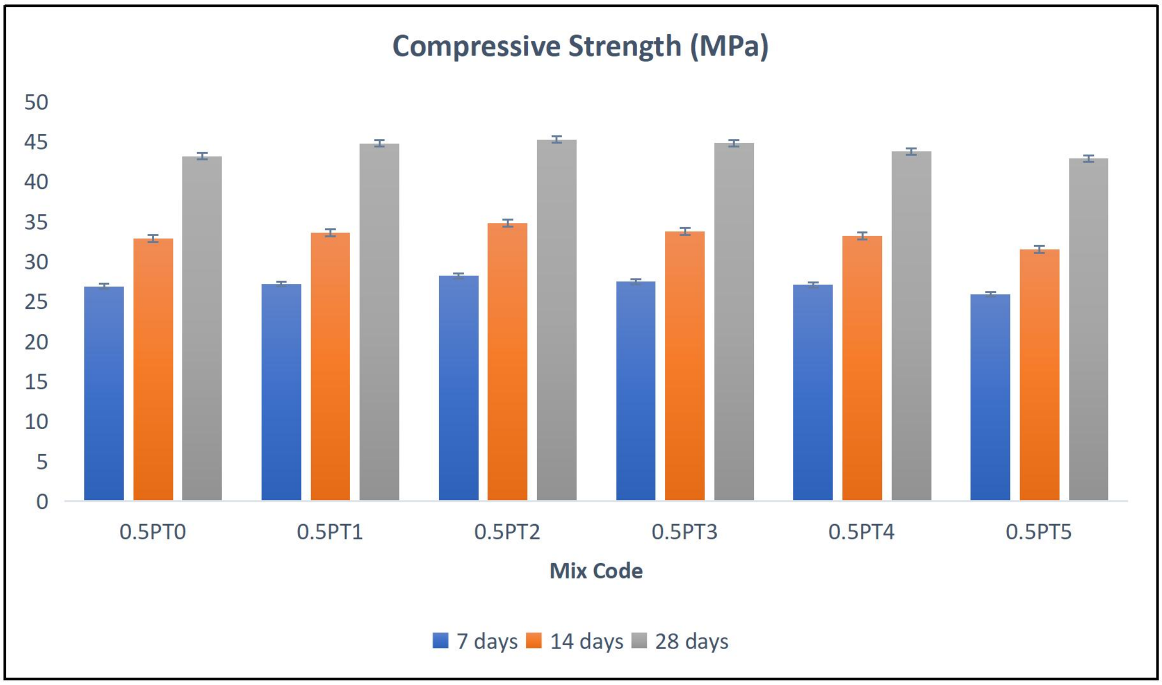

Figure 4. Compressive strength results data

Fig 4. shows the results of the compression test, which show that the concrete's compression strength can grow by up to 2% before declining with further increases. Compressive strengths for 1%, 2%, 03%, 4%, and 5% of the concrete are shown to deviate by 3.71%, 4.89%, 3.86%, 1.39% and –0.64%, respectively, from the control concrete when TiO_2 nanoparticles are added to the concrete at 28 days.

- **SPLIT TENSILE STRENGTH AND FLEXURAL STRENGTH**

Prisms measuring 150 x 150 x 700 mm and cylinders measuring 100 x 200 mm were cast and subjected to UTM testing to assess the split tensile strength and flexural behaviour at 7, 14 and 28 days. Test results data of split tensile strength showed in Table 5. According to the results, after adding 2% nano-TiO_2 and 0.5% polypropylene fiber to concrete, its splitting tensile strength improved by 19.48%, 9.29%, and 15.32% after 7, 14, and 28 days, respectively showed in Fig. 5. Because of the higher surface area and filling properties of nano TiO_2 and bonding between concrete ingredients and polypropylene fiber, concrete became more compact, which raised the material's splitting tensile strength [20].

Table 5: Compressive strength value determines through experimental study

Mix Code	Split Tensile Strength		
	7 days	14 days	28 days
0.5PT0	3.08	3.98	4.44
0.5PT1	3.24	4.23	4.78
0.5PT2	3.68	4.35	5.12
0.5PT3	3.28	4.28	4.89
0.5PT4	3.17	4.10	4.66
0.5PT5	2.99	3.88	4.24

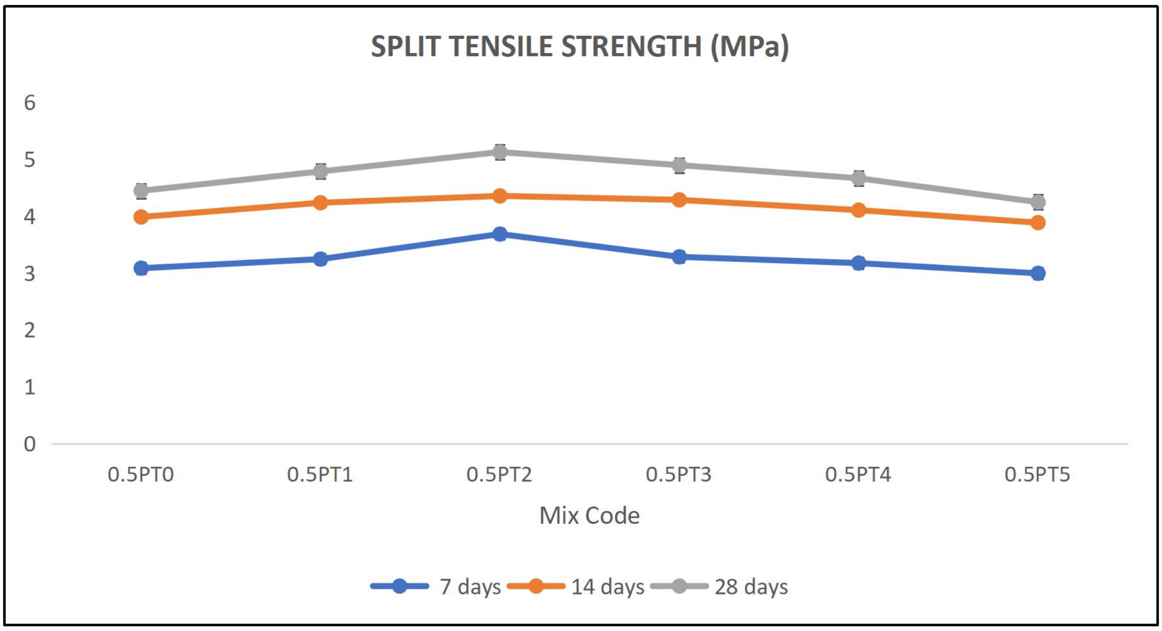

Figure 5. Split tensile strength results data

The flexural strength findings for various mixtures at 7, 14, and 28 days are displayed in Fig. 6. According to the findings, at 7, 14, and 28 days, the flexural strength of concrete enhanced by 21.27%, 13.22%, and 14.69% with the addition of 2% nano-TiO_2 and 0.5% polypropylene fiber, respectively. When the amount of polypropylene fiber in concrete increases, its flexural strength first rises and achieves its maximum value at 5.23 MPa for 2.0% nano TiO2 and 0.5% polypropylene fiber content after 28 days. After that, it decreases as the amount of polypropylene fiber in concrete increases. A few important elements work together to greatly boost the flexural strength of concrete. Polypropylene (PP) fibers, improve its overall flexural strength, reduce crack propagation, and increase its tensile strength and flexibility. Concrete's microstructure is enhanced by the addition of nanomaterials, such as nano titanium dioxide (TiO_2), which results in stronger bonds and better bonding. An ideal mix design is also very important, with the right amounts of aggregate and a balanced water-to-cement ratio. Higher flexural strength is a result of the concrete achieving its intended strength and durability through adequate curing. Premium cement, aggregates, and admixtures are examples of high-quality materials that yield improved overall performance, including increased flexural strength. Fig. 7. represented the mechanical test performance of specimens on compression testing machine (CTM) anf flexural testing machine.

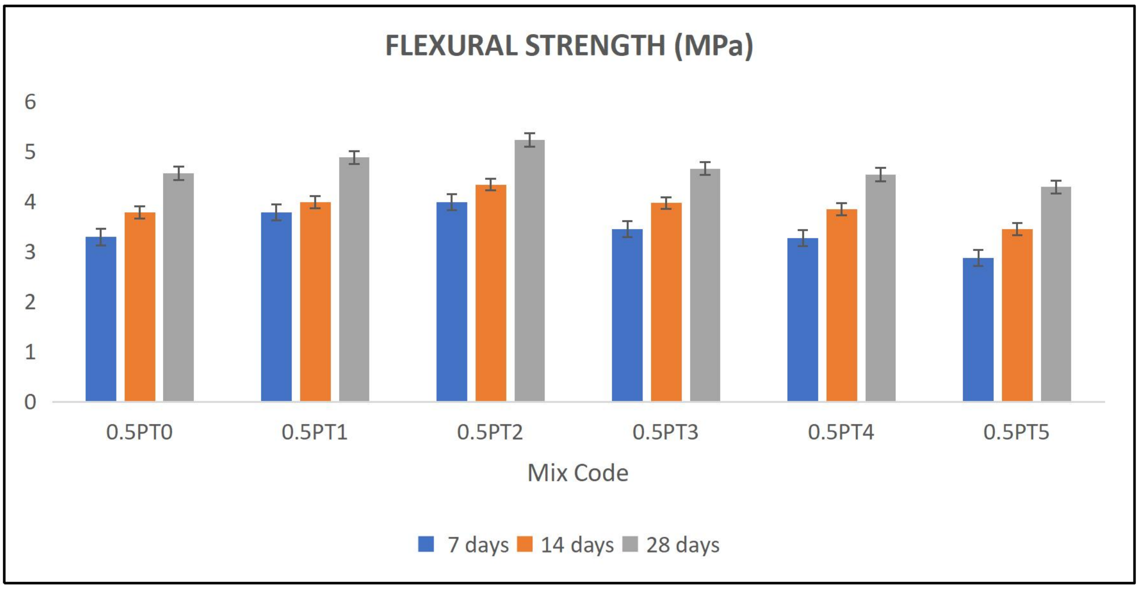

Figure 6. Flexural strength results data

Figure 7. Mechanical test performance on CTM and Flexural testing machine

- **MICROSTRUCTURAL ANALYSIS**

The layered calcium hydroxide (CH, or $Ca(OH)_2$, the amorphous and weakly crystalline calcium silicate hydrate (C-S-H), and the calcium aluminate/alumino-ferrite hydrate phases (AFm and AFt-type phases) are the main phase compositions of hydrated concrete. The main bind phase in the hardened concrete is C-S-H. Another significant ingredient is CH, which makes up 20–25% of the volume of hydrate products. The microstructures of the plain and optimally adjusted concrete samples are displayed in Fig. 8. The predicted function of fiber and nanoparticles is to establish a kind of network, bridging cracks to create a dense microstructure and toughening the reinforced concrete. As a result, the toughness of cementation matrices is greatly increased by fiber and nanoparticles. It appears that the creation of fibers and nanoparticle networks limits the growth of CH crystals and minimizes micro voids, which in turn reduces CH's size and orientation [20-21]. Consequently, the size and orientation of CH have been greatly reduced, and the microstructures and the aggregate-cement interfacial transition zone of nano TiO_2 are much denser with less micro-cracking than that of plain concrete. Consequently, there has been a noticeable decrease in water penetration and a significant increase in the compressive and flexural strengths values of nano TiO_2. Additionally, the networking effect that holds concrete aggregates together and stops cracks from spreading is produced by fibers and nanoparticles. Additionally, fibers would carry out the role of bridging cracks, absorbing a portion of the internal tensile stress and preventing the propagation of cracks once microcracks initially appear.

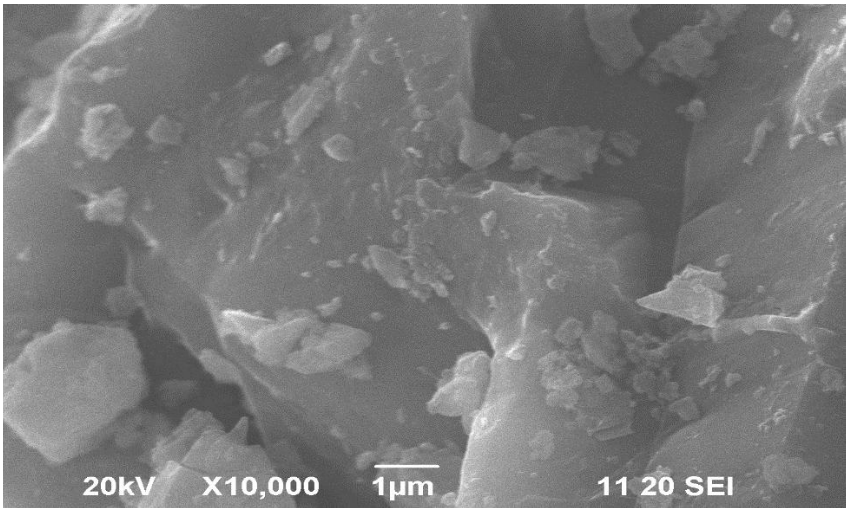

Figure 8. SEM image of concrete specimen of 0.5PT2

4. CONCLUSION

This study aims to investigate the effects of fiber and nanoparticles on the mechanical and physical characteristics of concrete. Concrete specimens mechanical strength can be effectively increased by adding 2% nano-TiO_2 with 0.5% polypropylene fiber. At 28 days, the concrete's flexural strength increases by 14.69%, its splitting tensile strength increases by 15.32%, and its compressive strength increases by 4.89%. The addition of fiber and nanoparticles can drastically change the microstructure of concrete by reducing the quantity, size, and orientation of CH crystals and micro voids as well as the voids and micro-cracking at the interface where the cement and aggregate meet. Condensing the microstructure of concrete and enhancing its mechanical and physical qualities are achieved by applying fiber and nanoparticles simultaneously, which creates a network to prevent the growth of CH crystalline.

REFERENCE

1. Behfarnia, K., Azarkeivan, A., & Keivan, A. (2013). The effects of TiO2 and ZnO nanoparticles on physical and mechanical properties of normal concrete.
2. Martins, T. M. D. R., Pacheco-Torgal, F., Miraldo, S., Aguiar, J. L., & Jesus, C. M. G. (2016). An experimental investigation on nano-TiO2 and fly ash based high performance concrete.
3. Reshma, T. V., Manjunatha, M., Bharath, A., Tangadagi, R. B., Vengala, J., & Manjunatha, L. R. (2021). Influence of ZnO and TiO2 on mechanical and durability properties of concrete prepared with and without polypropylene fibers. *Materialia*, *18*, 101138.
4. MEHDIPOUR, M. (2015). MODIFICATION OF PHYSICAL AND MECHANICAL PROPERTIES OF FIBER REINFORCED CONCRETE USING NANOPARTICLES. *Nanomaterials and Nanotechnology for Composites: Design, Simulation and Applications*, 59.
5. MEHDIPOUR, M. EFFECTS OF POLYPROPYLENE FIBERS AND NANOPARTICLES ON MICROSTRUCTURE OF FIBER REINFORCED CONCRETE.
6. Raza, A., Azab, M., Baki, Z. A., El Hachem, C., El Ouni, M. H., & Kahla, N. B. (2023). Experimental study on mechanical, toughness and microstructural characteristics of micro-carbon fibre-reinforced geopolymer having nano TiO2. *Alexandria Engineering Journal*, *64*, 451-463.
7. Martins, T. M. D. R., Pacheco-Torgal, F., Miraldo, S., Aguiar, J. L., & Jesus, C. M. G. (2016). An experimental investigation on nano-TiO2 and fly ash based high performance concrete.
8. Wei, X., Xiaoqing, W., & Chunmei, L. (2024). Effect of Nano-TiO2 and Polypropylene Fiber on Mechanical Properties and Durability of Recycled Aggregate Concrete. *International Journal of Concrete Structures and Materials*, *18*(1), 28.
9. Alsafy, M., Al-Hinai, N., & Alzebdeh, K. (2024, September). Mechanical Properties of Nano Date Palm versus Nano Titanium Dioxide Particles Reinforced Composites: Experimental Characterization. In *Materials Science Forum* (Vol. 1126, pp. 61-75). Trans Tech Publications Ltd.
10. Ying, J. (2023). Research on improving the properties and functionalities of recycled aggregate concrete. In *Multi-Functional Concrete with Recycled Aggregates* (pp. 127-143). Woodhead Publishing.
11. Feng, S., Jiang, Y., Lyu, J., Xiao, H., Zhang, Q., Song, R., ... & Ren, Z. (2024). Effect of nanosilica and fiber on mechanical properties and microstructure of recycled coarse aggregates road concrete. *Construction and Building Materials*, *428*, 136404.
12. Shuping, S. U. N., Yufen, D. U., Shu, S. U. N., Qingxian, Y. U., & Yongchun, L. I. (2024). Mechanical Properties of Recycled Concrete with Polypropylene Fiber and Its Bonding Performance with Rebars. *Materials Science*, *30*(3), 396-403.
13. Karthikeyan, B., & Dhinakaran, G. (2018). Influence of ultrafine TiO2 and silica fume on performance of unreinforced and fiber reinforced concrete. *Construction and Building Materials*, *161*, 570-576.
14. Yahaghi, J., Muda, Z. C., & Beddu, S. B. (2016). Impact resistance of oil palm shells concrete reinforced with polypropylene fibre. *Construction and building materials*, *123*, 394-403.
15. IS 8112 (2013): Specification for 43 grade ordinary portland cement. CED 2: Cement and Concrete
16. IS 4031 (1996) part (1-6) method of physical tests for hydraulic cement.
17. IS 2386 (1963) part (1-4) Methods of test for aggregates for concrete.

18. IS 383 (2016) Coarse and Fine Aggregate for Concrete – Specification.
19. IS 10262 (2019) Concrete Mix Proportioning — Guidelines
20. IS 516: Part 1: Sec 1 (2021) Testing of strength of hardened concrete section 1 compressive, flexural and split tensile strength (First Revision)
21. Li Hui, Z-m Hua, and Ou Jing-Ping, "Flexural fatigue performance of concrete containing nano-particles for pavement", International Journal of Fatigue, vol.29, 2007, p.1292 – 1301.
22. A.V. Girao, I.G. Richardson, C.B. Porteneuve, and R.M.D. Brydson, "Composition, morphology and nanostructure of C–S–H in white Portland cement pastes hydrated at 55 °C", Cement and Concrete Research, vol. 37, 2007, p.1571–1582.