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Effect of nano magnesium oxide and microsilica on the mechanical behavior of fiber-reinforced concrete

M. Etemadi, H. Beiraghi*

Department of Civil Engineering, Mahdishahr Branch, Islamic Azad University, Mahdishahr, Iran.

ABSTRACT: This study investigates the synergistic influence of nano magnesium oxide (nMgO), microsilica (silica fume), and polypropylene (PP) fibers on both fresh and hardened properties of concrete, aiming to propose an optimized hybrid mixture for structural applications. The novelty lies in the integrated, multi-scale approach—combining nano (nMgO), micro (microsilica) and macro (PP fibers) constituents—and a systematic experimental program covering 16 mix variants. Specimens were prepared with nMgO dosages of 0–2% and PP fibers of 0–1.4% by cement weight, while microsilica was kept at 4% replacement of cement. Mechanical tests (compressive, splitting tensile, flexural) were performed at 7, 28, and 90 days; water absorption was measured at 28 days. All reported values are the mean of replicates (n=3), and statistical dispersion is reported alongside mean values (raw data available upon request). The optimum performance was observed for the mix containing 0.5% nMgO and 0.8% PP fibers, which produced improvements up to 18% in compressive strength, 22% in splitting tensile strength, and 20% in flexural strength relative to the control mix, while reducing water absorption from 4.3% to 3.1%. Mechanistic interpretation attributes these gains to combined pore-filling and nucleation effects of nMgO, pozzolanic reaction of microsilica improving C–S–H content, and fiber-bridging improving post-crack behavior. Limitations and reproducibility (replicates, statistical reporting) are discussed. The outcomes demonstrate practical potential for enhanced durability and toughness in pavements, precast units, and other structural elements requiring improved tensile capacity.

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1- Introduction

Concrete is a heterogeneous material produced by mixing cement, aggregates of varying sizes, and water, each with distinct physical, chemical, and mechanical characteristics. The primary hydration products of cement are calcium hydroxide (CH) and calcium silicate hydrate (C-S-H), which largely govern the mechanical properties and porosity of concrete [1]. Despite extensive research on cement hydration, secondary reactions in concrete remain challenging to control. Cracking, often resulting from alkali–silica reactions, compromises durability and facilitates the ingress of gases and moisture, which accelerates steel reinforcement corrosion [2, 3].

In recent years, nanomaterials have gained significant attention in cementitious systems due to their ability to refine microstructure and enhance mechanical properties. Nanoparticles, owing to their small size and high specific surface area, act as nucleation sites, fill capillary pores, and promote pozzolanic reactions, resulting in a denser and stronger matrix [4]. Several nanomaterials—including $CaCO_3$, Al_2O_3, TiO_2, carbon nanotubes, and graphene oxide—have been shown to improve mechanical performance, reduce shrinkage, lower permeability, and enhance durability [5, 6]. Carbon-based nanomaterials such as nano graphite platelets improve matrix densification and facilitate crack bridging, further enhancing mechanical and durability characteristics.

Fiber reinforcement is another effective strategy to improve concrete toughness and durability. Studies on polypropylene (PP), steel, glass, and natural fibers demonstrate their role in improving tensile, flexural, and impact resistance, as well as controlling shrinkage [7–15]. PP fibers, in particular, are cost-effective, corrosion-resistant, and contribute significantly to crack control and durability enhancement [11–14]. Hybrid fibers, combining PP and steel or basalt fibers, have shown synergistic effects in improving strength, toughness, and thermal stability, particularly in magnesium oxychloride cement (MOC) systems [15-18].

Among nanomaterials, nano magnesium oxide (nMgO) has attracted attention due to its alkaline reactivity, nucleation potential, and ability to form magnesium silicate hydrate (M-S-H) phases, enhancing pozzolanic activity and matrix densification [16–18]. Incorporating 1–2% nMgO into concrete or cement mortar improves compressive, tensile, and flexural strengths significantly [18-22]. Magnesium oxychloride cement (MOC), known for rapid setting and high

*Corresponding author's email: Hamid.beiraghi@iau.ac.ir

Table 1. Properties of polypropylene fibers used in the mix.

Density	0.97
Diameter	38
Tensile strain to fracture%	3.5
Length mm	12
Degree of fusion (Celecus)	165
Water absorption %	0

Fig. 1. Polypropylene fibers used in the mix.

early strength, offers further potential when combined with nMgO and fiber reinforcement, although long-term stability and water resistance remain challenges [19].

Microsilica, an ultrafine byproduct of silicon production, exhibits strong pozzolanic behavior and fills capillary pores, enhancing the interfacial transition zone. When combined with nMgO, it promotes multi-scale microstructural refinement, accelerates hydration, and improves early strength development [19-23]. The synergistic interaction of fibers with nMgO and microsilica enables efficient load transfer and crack bridging under tensile and flexural stresses [22,23].

Previous studies often focus on individual components, such as nMgO, microsilica, or fiber reinforcement. Few investigations have addressed their combined effects in a hybrid system. This research fills that gap by evaluating a novel composite incorporating nMgO, microsilica, and polypropylene fibers. Compressive, tensile, and flexural strengths, along with water absorption, are assessed to quantify the mechanical and durability improvements. Compared to other nano additives like nano-silica or nano-alumina, nMgO provides unique advantages due to its chemical reactivity and multi-scale strengthening effects.

This integrative approach, combining nanoscale (nMgO), microscale (microsilica), and macroscale (fibers) components, represents a new pathway for designing high-performance, durable concrete suitable for structural applications. This study provides both qualitative and quantitative insights into the synergistic effects of multi-component hybrid cementitious systems, emphasizing practical relevance and potential applications in modern construction [23-24].

2- Material

2- 1- polypropylene fibers

Polypropylene (PP) fibers are widely used to enhance the mechanical performance and durability of concrete and plaster composites. Their incorporation improves bending, tensile, shear, and abrasion resistance. PP fibers exhibit excellent dispersion within the concrete matrix without settling, and their low density ensures minimal impact on the overall weight of concrete. In this study, fibers with a length of 12 mm were used, providing optimal reinforcement efficiency (Fig. 1). Detailed specifications of the polypropylene fibers are presented in Table 1.

Fig. 2. Nano magnesium oxide used in the mix.

2- 2- Nano magnesium oxide:

Magnesium oxide (MgO), commonly known as magnesia, is a naturally occurring white mineral and a major source of magnesium. It is recognized as a refractory material due to its excellent physical and chemical stability at high temperatures. MgO exhibits high thermal conductivity and low electrical conductivity, making it suitable for various engineering applications. In this study, magnesium oxide nanoparticles were employed to enhance the microstructure and mechanical properties of concrete. SEM images of the nanoparticles are shown in Fig. 3, and X-ray diffraction (XRD) analysis confirming particle composition and crystallinity is presented in Fig. 4. Detailed specifications of the nano MgO are listed in Table 2.

2- 3- cement

Commercial Portland cement Type II, conforming to Iranian Standard No. 389 [25], was used in all concrete mixes. Its chemical composition is summarized in Tables 3 and 4. The cement provided the primary binder for hydration reactions, contributing to strength development and matrix formation.

Table 2. Specification of Magnesium Oxide Nanoparticle specifications.

Mgo	Na	K	Ca
>98%	<2109ppm	<227ppm	<1815ppm
Morphology: polyhedral	Average Particle Size: 20nm	Specific Surface Area m2/g: <60	True density: 3.58 3g/cm
Color: white	Bulk density: 0.145 3g/cm		

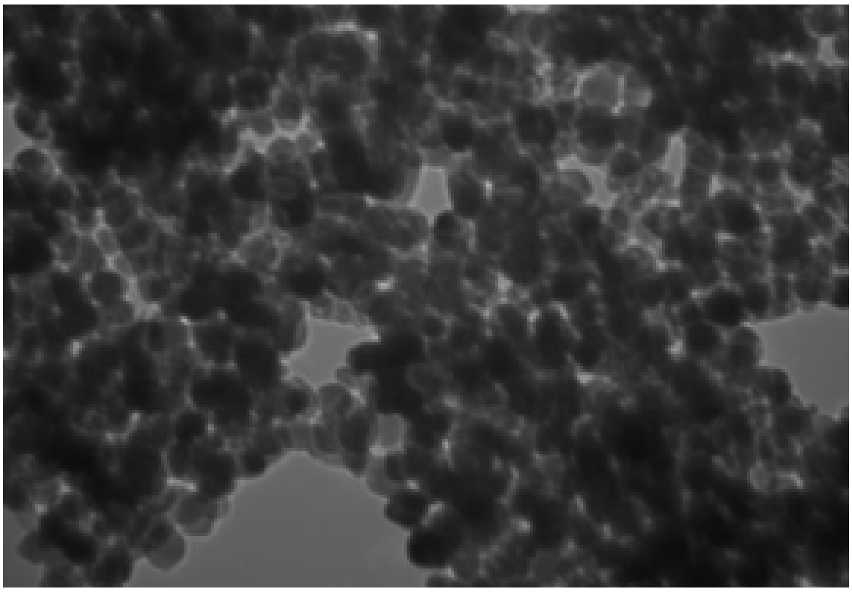

Fig. 3.Magnesium oxide nanoparticles used in the experiment from the perspective of an electron microscope (source: manufacturer)

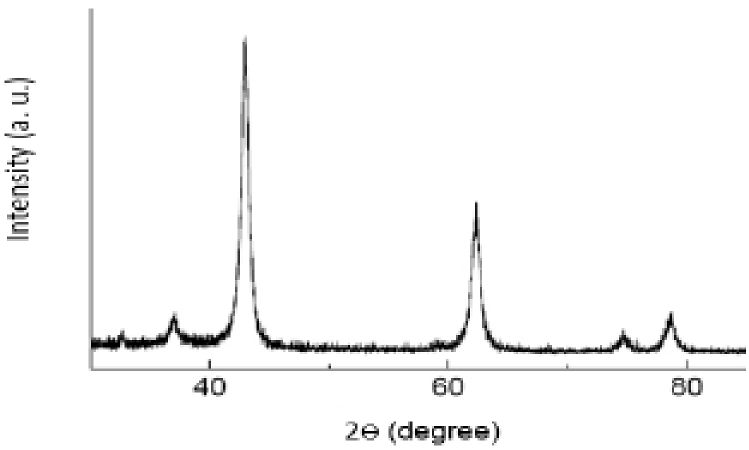

Fig. 4. Quantitative and qualitative X-ray analysis (XRD) of used magnesium oxide nanoparticles (source: manufacturer)

Table 3. Chemical composition of the cement used in the mix.

Elemental Composition	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	K_2O	Na_2O	LOI	IR
Content (%)	21.20	4.48	3.96	63.36	1.52	2.5	0.51	0.37	1.18	0.21

Table 4. Mineralogical characteristics of the cement used in the mix.

Elemental Composition	C_3S	C_2S	C_3A	C_4AF	CaO	Gypse
Content (%)	51.07	22.21	5.2	12.1	0.73	5

Table 5. Characteristics of micro silica powder used in the mix.

Name	Particle size (µm)	Bulk density (kg/m^3)	Degree of fusion (C)
Micro Silica	0.45~0.60	550~650	1250

2- 4- Microsilica powder

Light gray microsilica powder, containing approximately 92–95% silicon dioxide, was incorporated to improve concrete strength, durability, and resistance to freeze–thaw cycles. Due to its highly absorptive surface, a superplasticizer was used to maintain workability at low water-to-cement ratios. Insufficient dispersion of microsilica can lead to agglomeration, reduced workability, and poor compaction. High-speed mechanical mixing ensured uniform slurry formation.

The addition of microsilica enhances microstructural densification, reduces pore size, and strengthens the interfacial transition zone between cement paste and aggregates. Partial replacement of cement with microsilica also increases the electrical resistivity of concrete, reducing chloride ion penetration and improving corrosion resistance. Literature reports indicate optimal microsilica replacement levels between 4% and 12% by weight of cement [23]. Careful control of mixing and particle dispersion is critical to fully exploit its pozzolanic activity and mitigate adverse effects such as unwanted alkali-silica reactions.

2- 5- Aggregates

Aggregates used in this study complied with Iranian Standard No. 4977 [26]. Crushed limestone served as both fine and coarse aggregates. The specific gravity of the aggregates was 2.56, and the fine sand had a fineness modulus of 2.7 (Fig. 5). Particle size distribution is illustrated in Fig. 6. Aggregates provided a structural skeleton and contributed to load transfer and mechanical stability.

Fig. 1. Sand and coarse aggregates used in the test

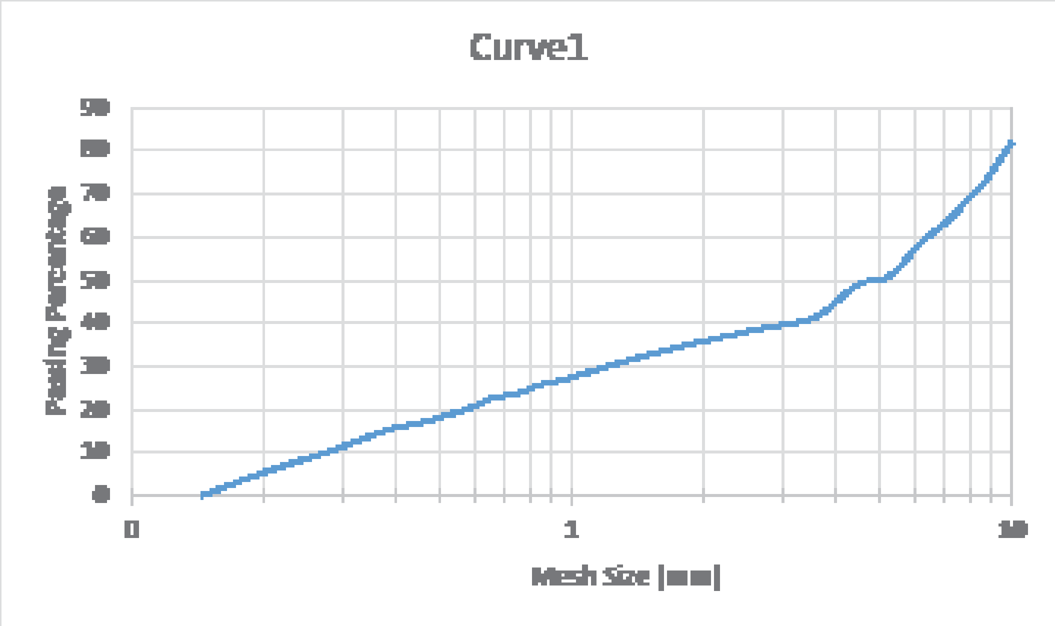

Fig. 6. Granulation diagram used in the experiment

2- 6- Water-Reducing Admixture

A third-generation naphthalene-based superplasticizer conforming to ASTM C494 standards [27] was used as a neutral water-reducing admixture. This admixture effectively prevents aggregate segregation and improves workability. It was added either after combining all concrete components or simultaneously with mixing water. The dosage was maintained at 2% by weight of cement.

2- 7- Water

Potable water from Mahdishahr city, with an average temperature of 20°C, was used in all mixes. The water was initially combined with nano MgO and microsilica to form a homogeneous slurry before addition to the dry mix, ensuring uniform dispersion and optimal hydration.

3- Mix Preparation

Polypropylene (PP) fibers are non-absorbent and can be uniformly dispersed within concrete. In this study, coarse aggregate, fine aggregate, and cement were initially dry-mixed. PP fibers were then gradually introduced and thoroughly dispersed to ensure uniform distribution throughout the mixture. After approximately 5 minutes of dry mixing to achieve homogeneity, the water slurry containing magnesium nano oxide (nMgO) and microsilica was added. It is important to note that the incorporation of fibers and nano MgO tends to reduce the workability of fresh concrete, necessitating careful mixing and the use of superplasticizers when required.

3- 1- Mix Ratio

The experimental program included varying dosages of nMgO and PP fibers to investigate their individual and combined effects. Nano MgO was incorporated at 0%, 0.5%, 1%, and 2% by weight of cement, while PP fibers were added at 0%, 0.2%, 0.8%, and 1.4% by weight of cement. Microsilica was used to enhance packing density by filling microvoids between fine nanoparticles and larger cement particles, thereby improving both fresh and hardened concrete properties. The control mix design was prepared following the National Method for Concrete Mix Design [23]. Detailed mix proportions for all 16 experimental mixtures are presented in Table 6.

3- 2- Specimen Preparation and Curing

Specimens were prepared according to BS 1881:1983 [28]. Cube molds were filled in three layers, with each layer compacted using a vibrating table, a vibrating hammer, or at least 15 blows with a steel tamper (25 × 25 mm^2). Compaction continued until complete consolidation was achieved to avoid segregation and weak surface layers. During molding, specimens were protected from vibration shocks and moisture loss.

After molding, the top surfaces of the cubes were finished with a trowel. Specimens were stored for 24 ± 4 hours at 25 ± 5°C and at least 90% relative humidity. Upon demolding, all specimens were cured in water at 20 ± 2°C until the testing age.

Table 6. Mix ratio of the specimens (mix proportions are by weight) (kg/M3)

Mix No.	Water	cement	sand	aggregate	Microsilica	Nano magnesium oxide	polypropylene
C1	160	378	790	1055	15	0	0
C2	160	378	790	1055	15	1.88468	0
C3	160	378	790	1055	15	3.76936	0
C4	160	378	790	1055	15	7.53872	0
C5	160	378	790	1055	15	0	0.74676
C6	160	378	790	1055	15	1.88468	0.74676
C7	160	378	790	1055	15	3.76936	0.74676
C8	160	378	790	1055	15	7.53872	0.74676
C9	160	378	790	1055	15	0	1.4224
C10	160	378	790	1055	15	1.88468	1.4224
C11	160	378	790	1055	15	3.76936	1.4224
C12	160	378	790	1055	15	7.53872	1.4224
C13	160	378	790	1055	15	0	49.784
C14	160	378	790	1055	15	1.88468	49.784
C15	160	378	790	1055	15	3.76936	49.784
C16	160	378	790	1055	15	7.53872	49.784

3- 3- Workability of Fresh Concrete

The workability of fresh concrete was evaluated using the slump test according to ASTM C143 [29]. The slump cone was filled in three layers, each tamped 20 times with a standard rod. The cone was lifted vertically, and the slump was measured.

The effect of nMgO and PP fibers on workability was evident. The control mix (without fibers or nMgO) exhibited a slump of 17 cm, whereas the mix containing 1.4% PP fibers and 2% nMgO showed a significantly reduced slump of 1 cm. Both PP fibers and nMgO decreased the workability of the concrete mixture, with nMgO having a more pronounced effect due to its high surface area and reactivity. Appropriate measures, such as using superplasticizers and thorough mixing, are therefore critical to ensure uniform dispersion and satisfactory workability.

4- Test of hardened concrete

4- 1- Compressive Strength Test

The compressive strength of concrete was determined using cubic specimens with dimensions of 150 × 150 × 150 mm³, tested under uniaxial compression using a compression testing machine. The loading rate was maintained at 25 MPa/min. Compressive strength was calculated as:

$$S = P/A \tag{1}$$

where P is the maximum applied load and A is the cross-sectional area of the specimen. Proper alignment and controlled loading ensured accurate and reproducible results.

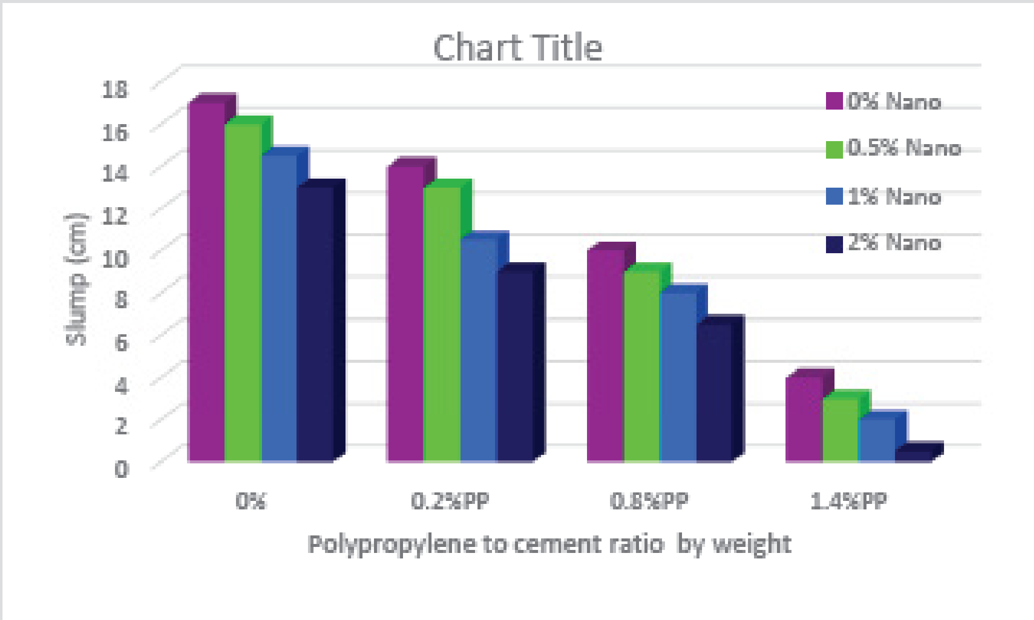

Fig. 7. Effect of magnesium oxide nanomaterial and fibers on fresh concrete slump.

4- 2- Tensile Splitting Strength Test

Splitting tensile strength was measured on cylindrical specimens using the Brazilian test. The theoretical tensile stress under diametrical compression is based on elastic theory for circular disks [30, 31]. The splitting tensile strength, Fct, was calculated by:

$$F_{ct} = \frac{2p}{\pi DL} \tag{2}$$

Fct is the tensile strength of concrete, P is the maximum test load, L is the length of the sample, and D is the diameter of the sample.

4- 3- Flexural Strength Test

Flexural tensile strength was measured using beam specimens under a center-point loading test. The beam was simply supported at both ends and loaded vertically at midspan until failure. The flexural strength, ft , also known as the modulus of rupture, was calculated by:

$$ft = Fl/bh2 \tag{3}$$

Where ft denotes concrete flexural strength; F and l are the failure load of the specimen and the distance between supports, respectively. b and h are the width and height of the beam specimen cross-section, respectively. This formula follows ASTM C293 [32].

4- 4- Water Absorption Test

Water absorption of hardened concrete was measured in accordance with ASTM C642-06 [33]. After curing for 28 days, samples were oven-dried at 100–110 °C for 24 hours and weighed (dry weight, m0). Then, the samples were immersed in water for 24 hours, removed, and weighed again (wet weight, m). Water absorption percentage was calculated using Equation (4):

$$absorption = \frac{m-m_0}{m_0} \times 100 \tag{4}$$

m =Wet sample weight

m0= dry sample weight

5- Compression Test Results

The effects of varying polypropylene fiber content and nMgO percentages on compressive strength were investigated individually and in combination. Cubic specimens were tested at 7, 28, and 90 days of curing. Specimens were removed from water curing, surface-dried while maintaining moisture, and tested according to Iranian Standard No. 6048.

5- 1- Effect of different nano percentages

5- 1- 1- Effect of Magnesium Nano Oxide on Compressive Strength without Polypropylene Fibers

Concrete samples containing various nMgO percentages but without fibers were tested. The addition of 0.5% nMgO increased compressive strength by approximately 12% at all ages. Beyond 0.5%, strength gradually decreased, likely due to nanoparticle agglomeration (Fig. 9).

Fig. 8. Compression testing

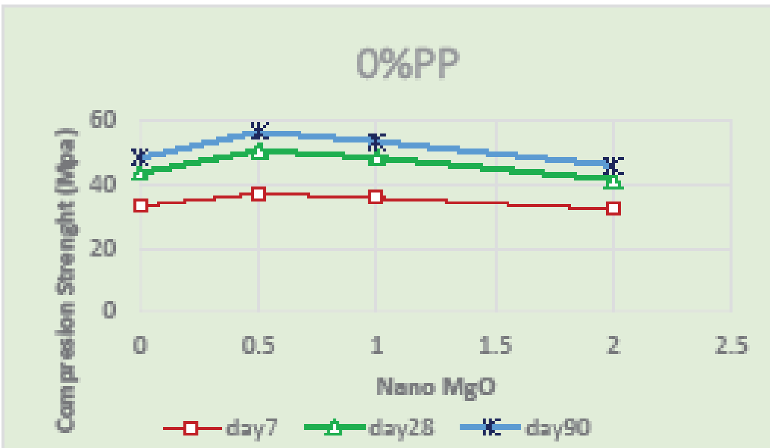

Fig. 9. The effect of nano magnesium oxide on compressive strength in the absence of polypropylene fibers

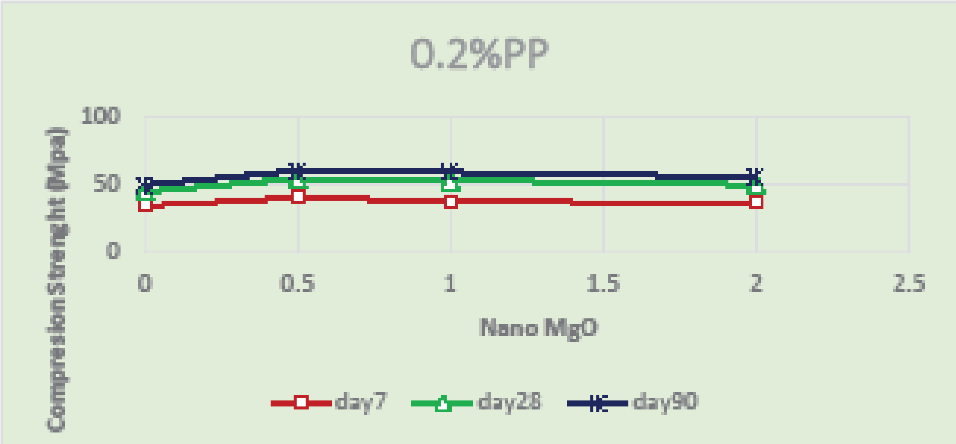

Fig. 11. Effect of nano magnesium oxide on compressive strength at the level of 0.8% of polypropylene fibers by the volume of cement

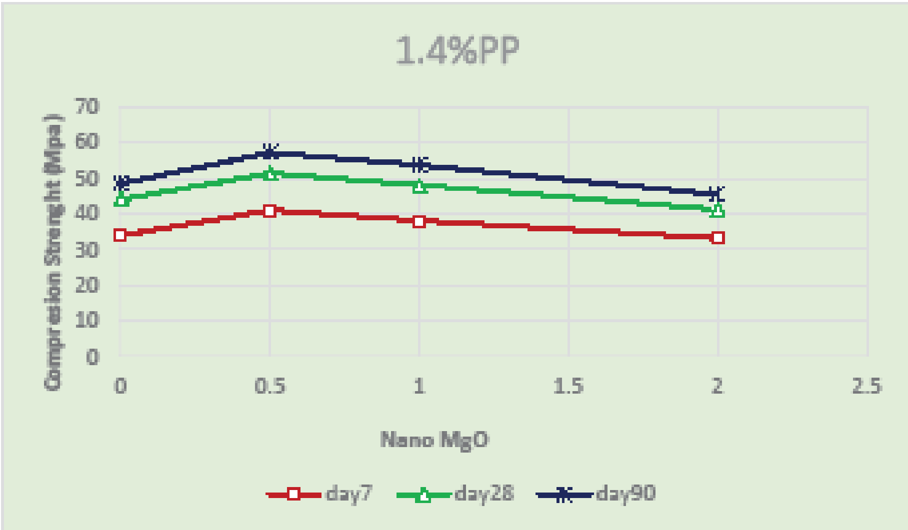

Fig. 12. Effect of nano magnesium oxide on compressive strength at the level of 1.4% of polypropylene fibers by the volume of cement

5- 1- 2- Effect of Nano Magnesium Oxide Addition with 0.2% Polypropylene Fibers

For samples containing 0.2% PP fibers, the compressive strength increased with nMgO up to 0.5%, after which a slight reduction was observed. This trend was consistent across 7, 28, and 90 days (Fig. 10).

5- 1- 3- Effect of 0.8% Polypropylene Fiber

Samples with 0.8% fibers showed peak compressive strength at 28 days with 1% nMgO, while at 7 days, the maximum strength occurred with 0.5% nMgO (Fig. 11).

5- 1- 4- With 1.4% polypropylene fiber

For 1.4% fiber content, the highest compressive strength was achieved with 0.5% nMgO, while increasing nMgO to 2% caused a gradual decline close to the control sample without nMgO (Fig. 12).

5- 2- Comparison of compression test results

Figure 13 compares all mixes, highlighting that the optimum combination is 0.5% nMgO with 0.8% PP fibers. Higher nMgO content reduces compressive strength, occasionally approaching the performance of mixes without nMgO.

5- 3- Failure Modes

Conventional concrete typically exhibits brittle failure characterized by sudden collapse due to microcrack propagation. Control samples without fibers or nMgO failed explosively. The addition of 0.5% nMgO produced a more ductile behavior due to microstructure densification, delayed crack initiation, and reduced microcrack coalescence. Excess nMgO (>0.5%) caused nanoparticle agglomeration, creating weak zones that promoted brittle failure.

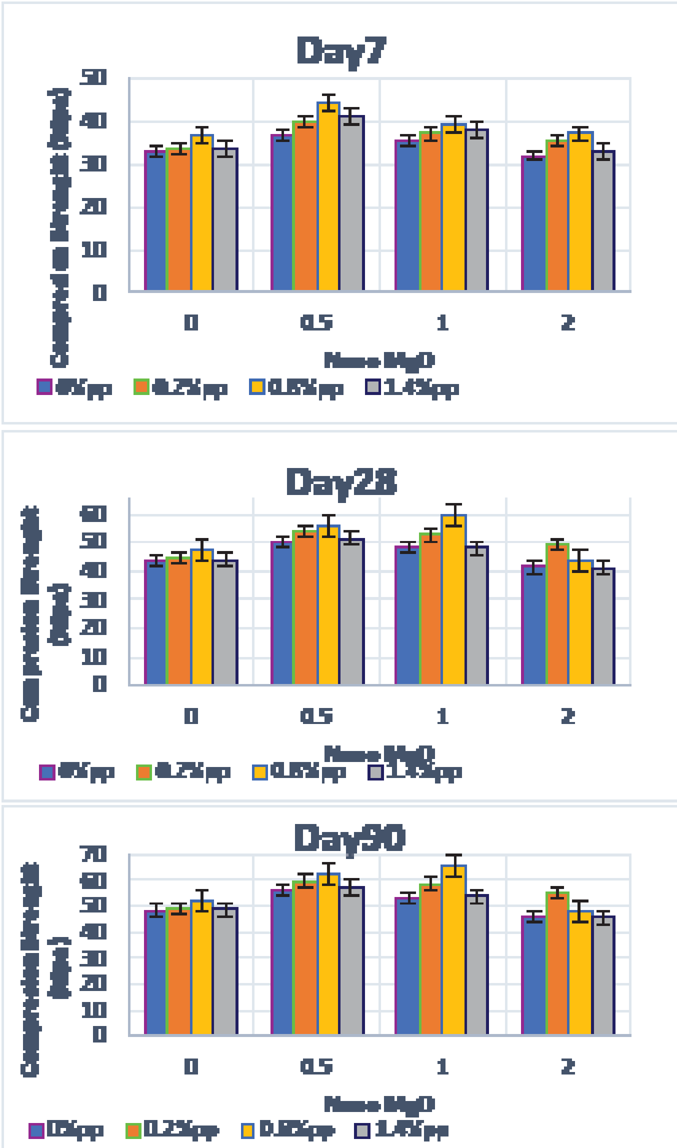

Fig. 13. Comparison of 7, 28, and 90-day compressive strength with different percentages of magnesium oxide nanomaterial and polypropylene fibers.

Polypropylene fibers improved post-cracking behavior. Samples with 0.8% fibers displayed pseudo-ductile failure, with microcracks bridged by fibers, crack widths controlled, and energy dissipated via fiber pull-out or rupture. The combination of fibers and 0.5–1% nMgO optimized both strength and toughness, converting the failure surface from a single fracture plane to a tortuous path.

6- Split Tensile Strength Results

Splitting tensile strength was evaluated using cylindrical specimens (150 mm diameter × 300 mm length) according to the Brazilian test at curing ages of 7, 28, and 90 days. After the designated curing period, specimens were removed from water, their surfaces dried with a towel, and diametrical compressive load was applied until splitting occurred. Tensile strength was calculated using the standard formula.

Results indicate that incorporating 0.5–1% nMgO significantly improves tensile strength at all curing ages. This enhancement is attributed to the nanoparticles filling microvoids in the cement matrix and promoting hydration, resulting in a denser and stronger matrix. The optimum polypropylene fiber content was determined to be 0.8% by cement weight (Fig. 14). Fibers bridged microcracks and limited crack propagation, further contributing to tensile performance. Figure 15 shows a fractured specimen after the splitting tensile test.

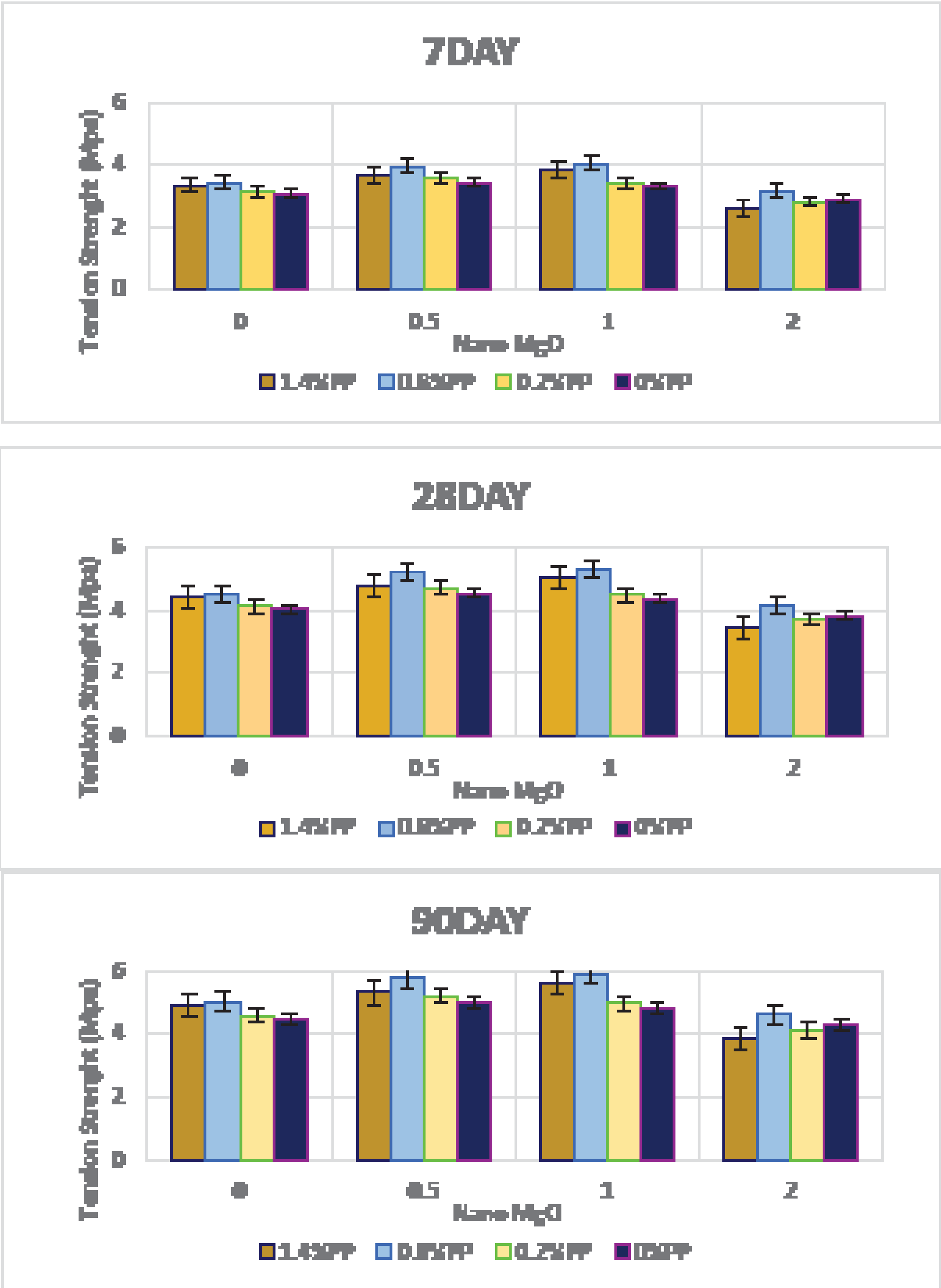

Fig. 14. Comparison of 7, 28 and 90-day splitting tensile strength with different percentages of magnesium oxide nanomaterial and polypropylene fibers.

Fig. 15. Concrete sample breaking in the splitting test

7- Concrete flexural strength

Flexural strength was measured on beam specimens (100 × 100 × 500 mm³) in accordance with standard methods for ordinary concrete. Beams incorporating various nMgO and PP fiber contents were tested at 7, 28, and 90 days of curing.

The results demonstrate that the combination of 1% nMgO and 0.8% PP fibers achieved the highest flexural strength. At 28 days, this combination produced approximately 1.25 times higher flexural strength than the mix containing 1% nMgO without fibers. Similar trends were observed at 7 and 90 days (Fig.16). The improvement is attributed to the synergistic effects of nMgO densifying the microstructure and fibers providing crack-bridging, energy dissipation, and enhanced post-cracking performance.

8- Water absorption

The water absorption of 28-day concrete specimens was evaluated in accordance with ASTM C642 [34]. For this purpose, standard cube samples were prepared. To assess the long-term water absorption, each specimen was first dried in an oven at 110 °C for ٢٤ hours, after which the dry mass (m_0) was recorded. Subsequently, the specimens were immersed in water for 24 hours, and the saturated surface-dry (SSD) mass (m) was measured.

Results show that nMgO reduces water absorption due to pore refinement and enhanced matrix densification. Concrete without nMgO or fibers exhibited approximately 4.3% water absorption, which decreased to 3.1% with 2% nMgO (Fig. 17).

Conversely, PP fibers tend to increase water absorption. In mixes without nMgO, increasing fiber content from 0% to 1.4% increased water absorption from 4.3% to 5.4%. This is attributed to the formation of additional interfacial transition zones (ITZs) around fibers, which can serve as pathways for water ingress.

Overall, the results highlight a trade-off between durability and mechanical performance: nMgO improves both mechanical properties and reduces permeability, while fibers enhance toughness and post-cracking behavior but may slightly compromise water tightness. Optimizing the combination of nMgO and fibers is therefore essential for high-performance concrete.

9- The relationship between compressive and tensile strength

The relationship between cubic compressive strength and splitting tensile strength of specimens with magnesium oxide nanomaterial is presented in Fig. 18. The fitted formula is as follows:

$$f_{sp} = 0.097 f_c\text{^}0.98$$

Where f_{sp} is splitting tensile strength and f_c Is the cubic compressive strength in MPa?

10- Discussion

The findings of this study highlight the significant potential of combining nano magnesium oxide, polypropylene fibers, and microsilica to enhance the mechanical and durability performance of cementitious composites. The observed improvement in compressive, tensile, and flexural strengths aligns with recent research investigating modifications of concrete matrices. For instance, He et al. demonstrated that fiber systems improve crack resistance and energy absorption capacity, while nano-additives contribute to matrix densification and strength enhancement [35]. The results in the present work confirm such synergistic behavior, particularly the increase in compressive strength at 0.5% nMgO and 0.8%

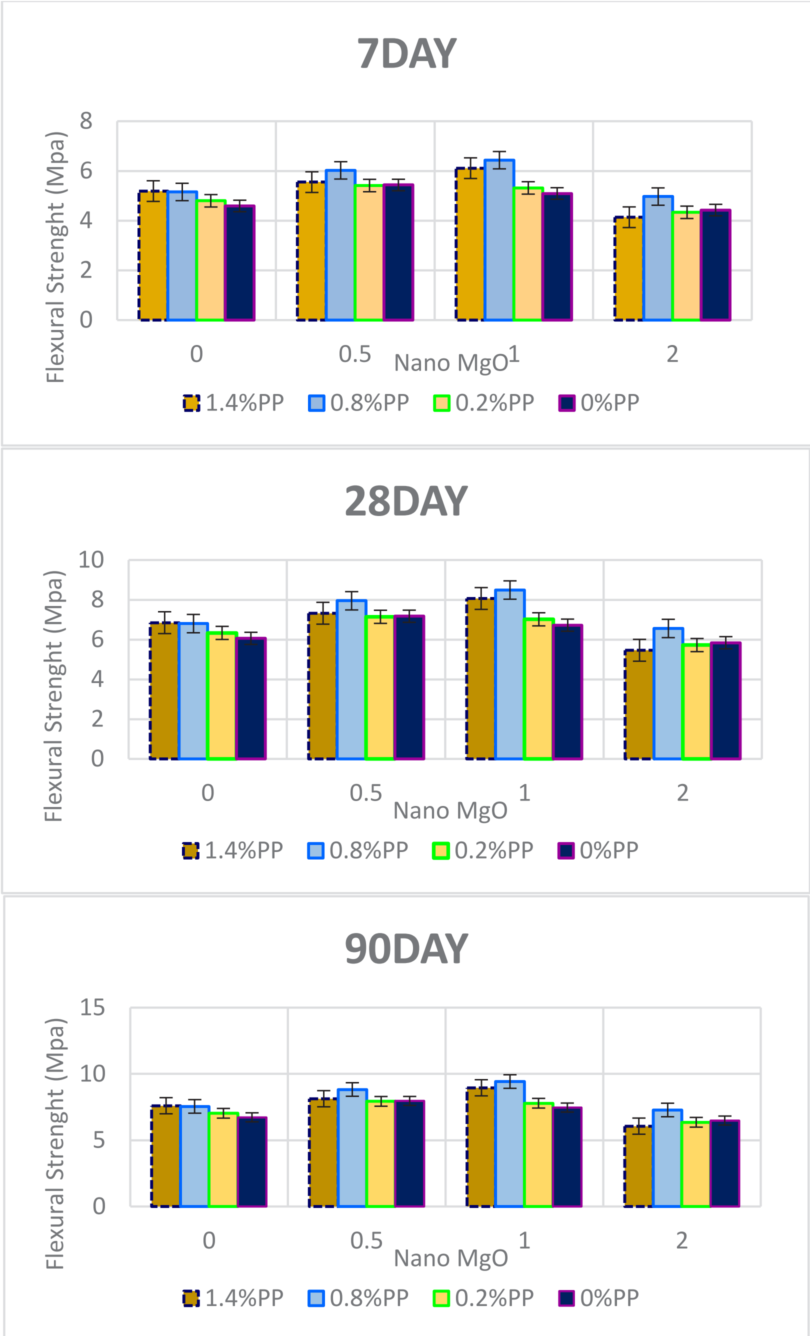

Fig. 16. Comparison of 7, 28, and 90-day flexural strength with different percentages of magnesium oxide nanomaterial and polypropylene fibers.

PPF, which mirrors the trends seen in hybridized concretes with optimized nanoparticle content.

The inclusion of nMgO influences the microstructure by acting as a nano-filler and an activator in the hydration process. As reported by Yuan et al., nano-MgO accelerates the formation of C–S–H gel and reduces calcium hydroxide crystals, leading to a more compact and homogeneous matrix [36]. This behavior is inferred in our study through the reduced water absorption and improved mechanical performance. Furthermore, the interaction between nMgO and microsilica can result in a pozzolanic reaction that further consumes $Ca(OH)_2$ and contributes to the strength and durability of the concrete matrix, consistent with the findings of [37], who observed that the addition of silica-rich nano additives improved both compressive strength and microstructural integrity.

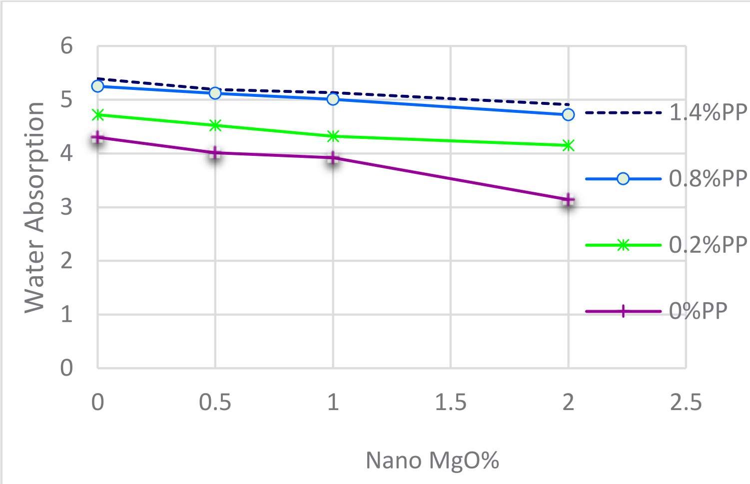

Fig. 17. The water absorption of 28-day concrete specimens

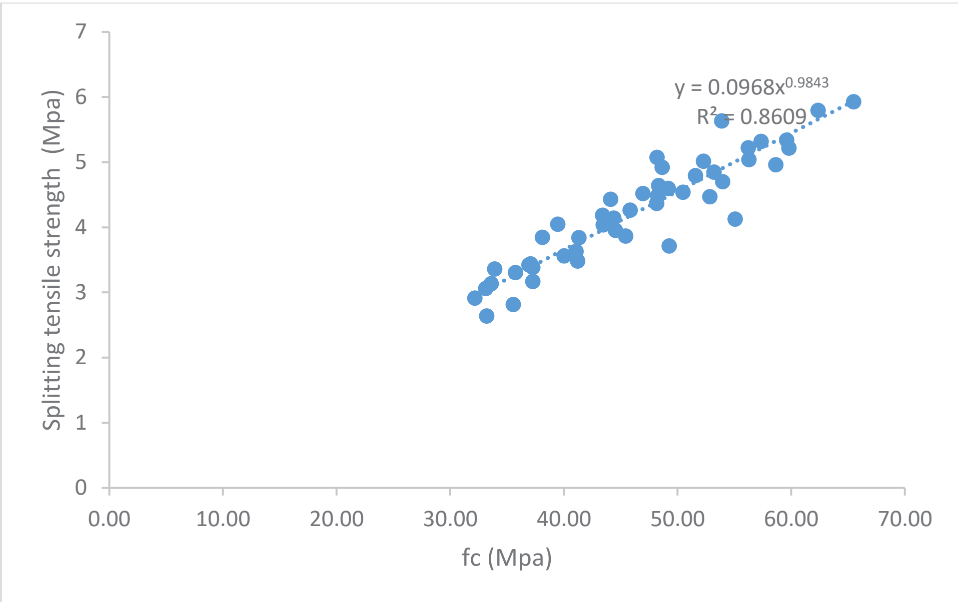

Fig. 18. The relationship between compressive strength and splitting tensile strength

The practical implications of this study are notable. The reduction in water absorption from 4.3% to 3.1% implies a significant improvement in concrete's resistance to water ingress, which is critical for durability in aggressive environments. Additionally, the enhanced tensile and flexural strengths provided by the system suggest improved performance under service loads and a reduced likelihood of early-age cracking. Deogekar and Andrawes also emphasized the benefit of hybrid confinement systems, where fibers control cracking while nano additives strengthen the matrix-an approach that aligns with the outcomes observed in our study [37].

In conclusion, the simultaneous incorporation of nMgO, PPF, and microsilica leads to measurable improvements in concrete performance due to combined physical, chemical, and mechanical mechanisms. These findings contribute to the ongoing advancement of high-performance cementitious composites for durable infrastructure applications.

11- Conclusion

This study investigated the combined effect of nano magnesium oxide (nMgO) and polypropylene (PP) fibers on the mechanical and durability properties of concrete. The experimental results indicate that the hybrid inclusion of nMgO and fibers significantly enhances compressive, splitting tensile, and flexural strengths while reducing water absorption under optimized conditions.

The optimal mix design was determined as 0.5% nMgO by cement weight and 0.8% PP fibers by volume. At this ratio, concrete exhibited the best balance of mechanical performance. The improvement can be attributed to multi-scale reinforcement: nMgO densifies the microstructure and promotes hydration, whereas fibers provide effective crack-bridging, delaying microcrack propagation and enhancing post-cracking behavior. The incorporation of fibers and nanoparticles affects workability. Increasing the dosages of PP fibers and nMgO reduced slump and complicated fresh concrete handling, due to the high surface area and water demand of nMgO and the physical entanglement of fibers. Mitigation strategies include using high-range water-reducing admixtures (superplasticizers), optimizing mixing procedures, and careful casting to ensure full compaction and uniformity.

For practical applications, this hybrid concrete is recommended for structural elements where durability and tensile performance are critical, such as industrial flooring, tunnel linings, precast components, and pavement slabs. In situations with limited vibration capacity or where workability is crucial, fiber content should generally remain below 1% and be complemented with appropriate admixtures.

Overall, this study provides new insights into the synergistic effects of nMgO and polypropylene fibers, offering a practical pathway for designing high-performance concrete with improved mechanical behavior and durability.

Data availability statement: Data from this research are available upon request.

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