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Experimental Analysis of Nano $CaCO_3$ and Polyethylene Terephthalate in Cementitious Composites

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Abstract: This research investigates the impact of using polyethylene terephthalate (PET) granules in place of fine aggregate and nano calcium carbonate ($CaCO_3$) particles as a partial replacement for cement on the microstructure and mechanical performance of M40 grade concrete. Nano $CaCO_3$, a naturally occurring material, possesses a finer particle size compared to cement, which enhances the particle packing and provides a spacer effect within the mix. Recycled PET waste in granular form contributes to sustainable construction by reducing reliance on natural aggregates. The study evaluates compressive strength, split tensile strength, and flexural strength at 7, 14, and 28 days of curing to assess both early and later-age performance. Results indicate that combining PET and nano $CaCO_3$ can lead to the development of lightweight, high-strength, and eco-friendly concrete, aligning with the goals of durable and sustainable infrastructure.
Keywords: Recycled PET Granules, Nano Calcium Carbonate ($CaCO_3$), M40 Grade Concrete, Microstructure, Fine Aggregate Replacement, Cement Replacement.

I. INTRODUCTION

The construction industry, a fundamental pillar of global infrastructure development, is continually exploring innovative materials and technologies to improve the performance and longevity of concrete. As environmental sustainability becomes increasingly critical, researchers are actively seeking methods to enhance concrete properties while minimizing ecological impact. This study aims to assess the mechanical performance of concrete modified with nano calcium carbonate ($CaCO_3$) and polyethylene terephthalate (PET), focusing on improving both structural integrity and environmental sustainability. Concrete, a widely used construction material, typically consists of cement, aggregates, water, and various admixtures. The inclusion of fine particles significantly influences its workability and strength.

Traditionally, natural sand and other fine aggregates are employed, but their extraction poses serious environmental risks. In response, attention has shifted towards the use of alternative materials that not only enhance concrete performance but also reduce its environmental footprint. PET, predominantly sourced from discarded plastic bottles, is a major component of plastic waste accumulating in landfills. Between 2000 and 2020, global plastic production surged from 180 million to 360 million tons. Plastics constitute approximately 8–12% of municipal solid waste, though this proportion varies by country due to differences in lifestyle, income levels, and waste management practices.

Previous studies have incorporated cost-effective carbon-based materials into cementitious systems. For instance, Restuccia et al. (2016) experimented with pyrolyzed food waste particles as nano- and micro-inert aggregates in concrete. Cosentino et al. (2019) investigated standardized biochar derived from pyrolyzed biomass, aiming for potential industrial-scale production of cement–biochar composites. Their findings indicated that adding pyrolyzed nanoparticles improved concrete's flexural strength, fracture energy, and ductility. Particle size has a profound effect on concrete properties; smaller particles generally lead to better mechanical outcomes (Restuccia et al., 2018; Ferro et al., 2014, 2015). Nanoparticles, due to their large surface area-to-volume ratio, ensure more effective interaction with the cement matrix, contributing to denser microstructures and reducing permeability. This ultimately enhances durability, as documented by researchers like Sanchez et al. (2010) and Shaikh et al. (2014). Nanotechnology in cement-based materials has gained traction in recent years.

Various nanoparticles have been studied for their potential benefits, including silica (SiO_2) (Sobolev et al., 2009), ferric oxide (Fe_2O_3) (Khoshakhlagh et al., 2012), titanium dioxide (TiO_2) (Daniyal et al., 2019), aluminum oxide (Al_2O_3) (Nazari et al., 2010), and calcium carbonate ($CaCO_3$) (Hashim et al., 2018; Supit et al., 2014).

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Nano $CaCO_3$, in particular, has shown promise due to its physical roles such as filler and nucleation effects and its chemical interactions within the cement matrix. Despite its benefits, nano $CaCO_3$ can experience agglomeration, which may limit its positive influence (Cao et al., 2019).

Nonetheless, studies have shown that its addition does not harm concrete strength. On the contrary, it can enhance early-age strength, accelerate hydration, and improve durability (Camiletti et al., 2013).

A potential solution to the cement industry's carbon footprint involves capturing carbon dioxide emissions and repurposing them to produce cement additives and nanofillers. This concept of a circular economy in cement production envisions the creation of near-zero-emission concrete materials.

Cosentino et al. (2019) demonstrated this approach by synthesizing nano-sized calcite particles through a carbonation process in a packed bed reactor, using calcium oxide and CO_2. These particles, when introduced into concrete mixtures in varying amounts, improved flexural and compressive strength after 7 days of curing—peaking at a 2% addition. However, at 28 days, strength diminished in samples with higher $CaCO_3$ content, likely due to excessive particle aggregation, which can reduce the filler efficiency. This behavior indicates that while nano $CaCO_3$ accelerates hydration by acting as nucleation sites, its optimal dosage is critical to maintain long-term performance.

II. MATERIALS AND METHODS

A. Cement

Ordinary Pozzolana Cement (OPC) was used for all phases of the investigation. Its physical properties conform to the requirements specified in IS: 1489-2015, confirming compliance with the standard limits as presented in Table 1.

Table 1: Physical properties of cement

S. No.	Name of Test	Result
1	Fineness modulus (by dry sieving)	6.21
2	Consistency Test	30%
3	Initial Setting time	48 minutes
4	Final Setting time	310 minutes
5	Specific gravity	3.09

B. Fine Aggregate

In this study, river sand classified under Zone II with a fineness modulus of 2.62 was used as fine aggregate. The selected material complies with the provisions of IS 383:2016. The physical properties of the fine aggregate are detailed in Table 2.

Table 2: Physical properties of fine aggregates

S. No.	Properties	Results
1.	Specific gravity (SSD based)	2.52
2.	Water absorption	1.67%
3.	Fineness modulus	2.62
4.	Silt content	1 %
5.	Sieve analysis	Zone II

C. Coarse Aggregate

Natural coarse aggregates with a nominal size of 20 mm were used in this study, meeting the requirements specified in IS 383:2016. The physical characteristics of the coarse aggregate are provided in Table 3.

Table 3: Physical properties of Coarse aggregates

S. No.	Property	Results
1.	Specific gravity	2.89
2.	Water absorption	0.5 %

D. Nano CaCO3 and PET

Characteristics properties of Nano CaCO3and PET are given in the table 4 and 5.

Table 4: Characteristics of CaCO3 nanoparticles

Particle size Average (nm)	Purity (%)	Manufacturer
15-40nm	98%	Qualigens

Table 5: Characteristics of PET used in the experimental work

Grade	Density	Manufacturer	Granule Size
B52A003	0.954 g/cm3	Gail India G-Lex	≤ 4.75 mm

E. Mix design and casting

The M40 grade concrete mix was designed in accordance with the guidelines provided in IS: 10262–2019 and IS: 456–2000. The concrete was prepared using a mechanical mixer based on the specified mix proportions. A constant water-to-cement ratio of 0.37 was maintained throughout the experiment. Nano calcium carbonate ($CaCO_3$) was incorporated into the mix in varying proportions from 0% to 3%, while recycled PET was added at a fixed rate of 10%. To ensure the desired workability, a superplasticizer with a specific gravity of 1.08 was used. The replacement of cement with nano $CaCO_3$ was carried out in incremental steps, ranging from 0% to 3%, alongside the constant PET addition. The target mean compressive strength was set at 48.25 N/mm². Workability was evaluated using the slump test, with a target slump of 100 mm, under conditions classified as severe supervision. The waste materials were incorporated as per the recommendations of IS: 10262–2019 and IS: 456–2000. Coarse aggregates of 20 mm nominal size were used in the mix. Following the mixing process, the fresh concrete was cast into steel moulds measuring 150 mm × 150 mm × 150 mm.

F. Test Procedure

Concrete specimens were evaluated for strength parameters in accordance with relevant Indian Standard codes. Compressive strength tests were carried out on cube specimens measuring 150 × 150 × 150 mm, as per IS 516 (Part-1/Sec-1): 2021. Split tensile strength was determined using cylindrical specimens of 150 mm diameter and 200 mm height, following the procedures outlined in IS 5816:1999. The compressive strength was measured using a compression testing machine, applying a loading rate of 14 N/mm²/min in accordance with the standard. For split tensile strength, a loading rate of 1.2 N/mm²/min was employed, adhering to the guidelines of IS 5816:1999. Flexural strength, a key indicator of a beam's load-carrying capacity in structural applications, was tested using a loading rate of 0.1 kN/sec. All specimens were cured in potable water for 7, 14, and 28 days, following the curing recommendations provided in IS 516:2021.

III. RESULTS AND DISCUSSION

A. Fresh Concrete Properties

The fresh density of Nano $CaCO_3$ concrete without any replacement (NC0) was recorded as 2518 kg/m³. For the modified mixes, the fresh densities were observed as follows: 2411 kg/m³ for NC2, 2401 kg/m³ for NC3, 2350 kg/m³ for NC4, and 2330 kg/m³ for NC5, as summarized in Table 8. Compared to the control mix (NC0), these values indicate a reduction in fresh density ranging from 0.60% to 38.84%, as illustrated in Figure 1.

Figure 1: Fresh density

B. Compressive Strength Nano CaCO3 Concrete

The compressive strength of concrete mixes incorporating 10% PET and varying proportions of nano $CaCO_3$ (ranging from 0% to 3%) as a replacement for fine aggregate was evaluated at curing intervals of 7, 14, and 28 days. The variation in compressive strength across these curing periods is graphically illustrated in Figure 2. For the control mix (NC0), the compressive strengths were recorded as 33.62 N/mm² at 7 days, 44.60 N/mm² at 14 days, and 51.62 N/mm² at 28 days, as detailed in Table 9. The results indicate that increasing the nano $CaCO_3$ content leads to a progressive reduction in compressive strength. This decline can be attributed to the lower shell strength of hollow nano $CaCO_3$ particles, which are more prone to cracking under higher stress levels.

As a result, their increased presence negatively impacts the overall strength of the concrete. The compressive strength data for all curing durations is presented in Figure 2.

Figure 2: Compressive strength

C. *Split Tensile Strength Nano $CaCO_3$ Concrete*

Split tensile strength assesses the ability of concrete to withstand tensile stresses applied perpendicular to the axis of loading. The variation in split tensile strength for different nano $CaCO_3$ concrete mixes at curing intervals of 7, 14, and 28 days is illustrated in Figure 3. In this study, nano $CaCO_3$ was used as a partial replacement for fine aggregate in varying proportions from 0% to 5%. The trend in split tensile strength closely mirrors that of compressive strength. At 28 days, the recorded split tensile strengths were 4.14 N/mm² for NC0, 4.05 N/mm² for NC1, 3.98 N/mm² for NC2, 3.80 N/mm² for NC3, 3.60 N/mm² for NC4, and 3.46 N/mm² for NC5. The complete data for 7-day, 14-day, and 28-day split tensile strengths are presented in Figure 3.

Figure 3: Split Tensile Strength

D. *Flexure Strength Nano CaCO3 Concrete*

Flexural strength is a critical parameter that reflects concrete's capacity to resist bending or flexural stresses. Similar to the trends observed in compressive and split tensile strengths, the flexural strength also shows a consistent pattern of variation. The flexural strength results at 28 days are presented in Figure 4. The control mix (NC0) achieved a flexural strength of 4.51 N/mm². For the concrete mixes containing nano $CaCO_3$, the 28-day strengths were 4.26 N/mm² for NC1, 4.05 N/mm² for NC2, 3.84 N/mm² for NC3, 3.65 N/mm² for NC4, and 3.47 N/mm² for NC5. The flexural strength values for 7, 14, and 28 days are comprehensively shown in Figure 4.

Figure 4: Flexural Strength

IV. CONCLUSION

An in-depth evaluation was carried out to study the effect of nano calcium carbonate ($CaCO_3$), used in varying proportions from 0% to 5%, as a partial replacement for fine aggregate in concrete. The compressive strength results varied depending on the percentage of nano $CaCO_3$ added, displaying no consistent trend across all mixes. At higher replacement levels, the improvement in mechanical properties was limited. This reduction in performance is likely due to poor dispersion of nano particles caused by agglomeration within the slurry and cement matrix.

Previous studies have indicated that nano $CaCO_3$ can accelerate the hydration process of cement, thereby enhancing early-age strength. In the current investigation, the mix containing 2% nano $CaCO_3$ showed the most favorable results, underlining the potential of nano $CaCO_3$ to improve the mechanical characteristics of cementitious materials when optimally used.

The key findings from this study are summarized below:

1) The fresh density of the concrete mix with 5% nano $CaCO_3$ (NC5) was found to be 34.46% lower compared to the control mix (NC0). The density of the concrete modified with nano $CaCO_3$ ranged from 2518 kg/m³ to 2308 kg/m³. Additionally, workability decreased as the nano $CaCO_3$ content increased.
2) Although the compressive strength of concrete incorporating nano $CaCO_3$ was lower than that of NC0, the mix with 2% nano $CaCO_3$ (NC2) still met the target mean strength requirements.
3) The split tensile strength of the nano $CaCO_3$ concrete showed a minimum reduction of 2.18% in NC1 compared to NC0.
4) A minimum reduction of 5.2% in flexural strength was observed in NC1 when compared with the control mix.
5) The inclusion of PET granules up to 10% had no significant impact on the workability of the concrete mix. However, increasing PET content beyond this point led to a slight decrease in workability. Similarly, the density of the mix decreased with higher PET content due to the lower specific gravity of PET compared to natural sand.

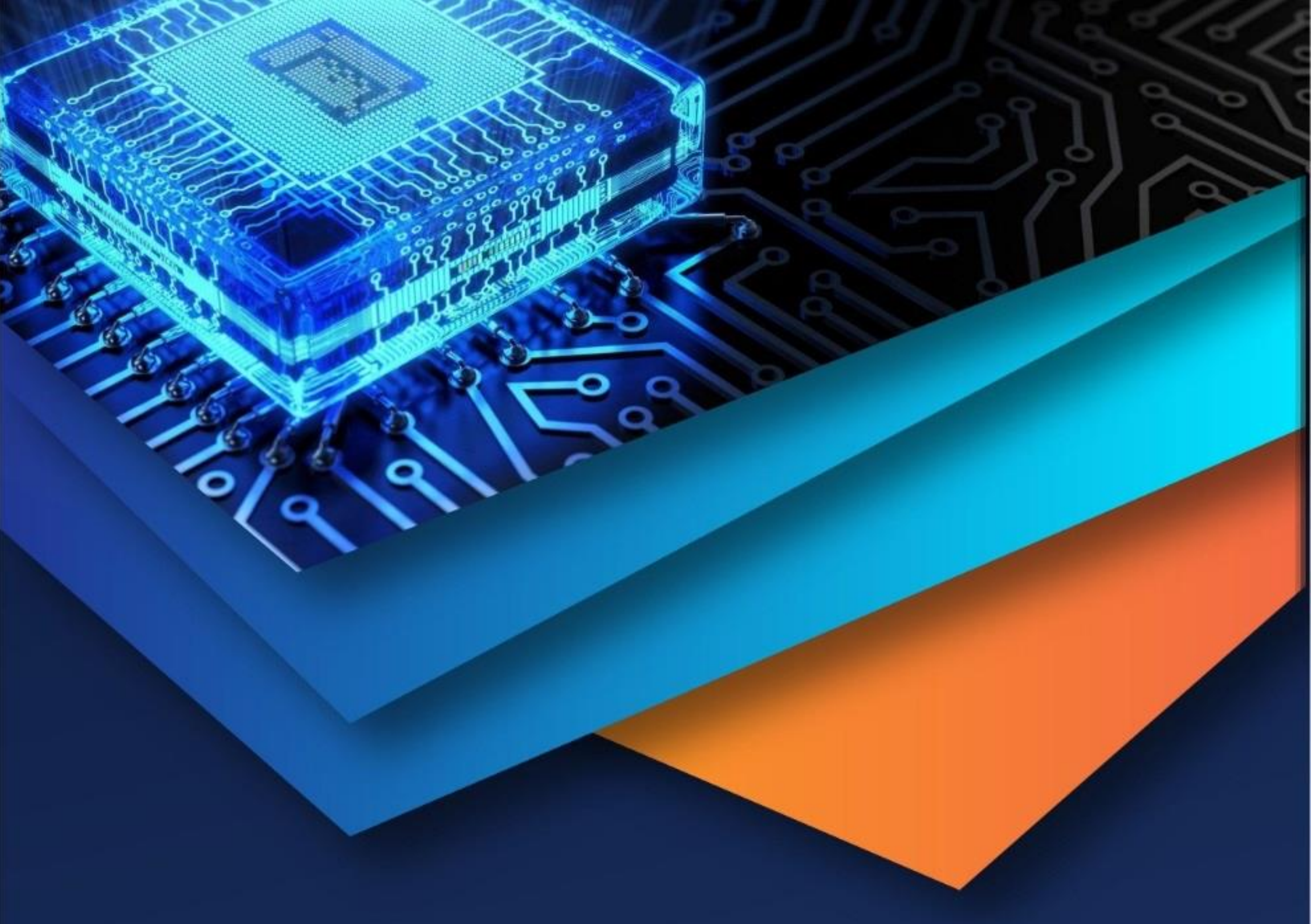
REFERENCES

[1] H. Mohammadhosseini, S.P. Ngian, R. Alyousef, M.M. Tahir, Synergistic effects of waste plastic food tray as low-cost fibrous materials and palm oil fuel ash on transport properties and drying shrinkage of concrete, J. Build. Eng. 42 (2021), 102826, https://doi.org/10.1016/j.jobe.2021.102826.

[2] M. Batayneh, I. Marie, I. Asi, Use of selected waste materials in concrete mixes (doi: https://doi.org/), Waste Manag. 27 (12) (2007) 1870–1876, https://doi.org/10.1016/j.wasman.2006.07.026.

[3] W. Ferdous, A. Manalo, R. Siddique, P. Mendis, Y. Zhuge, H.S. Wong, W. Lokuge, T. Aravinthan, P. Schubel, Recycling of landfill wastes (tyres, plastics and glass) in construction–A review on global waste generation, performance, application and future opportunities (doi: https://doi.org/), Resour., Conserv. Recycl. 173 (2021), 105745, https://doi.org/10.1016/j.resconrec.2021.105745.

[4] S.L. Wong, N. Ngadi, T.A.T. Abdullah, I.M. Inuwa, Current state and future prospects of plastic waste as source of fuel: a review (doi: https://doi.org/), Renew. Sustain. Energy Rev. 50 (2015) 1167–1180, https://doi.org/10.1016/j.rser.2015.04.063.
[5] R.M. Bajracharya, A.C. Manalo, W. Karunasena, K.T. Lau, Characterisation of recycled mixed plastic solid wastes: coupon and full-scale investigation (doi: https://doi.org/), Waste Manag. 48 (2016) 72–80, https://doi.org/10.1016/j.wasman.2015.11.017.
[6] H. Aslani, P. Pashmtab, A. Shaghaghi, A. Mohammadpoorasl, H. Taghipour, M. Zarei, Tendencies towards bottled drinking water consumption: challenges ahead of polyethylene terephthalate (PET) waste management, Health Promot. Perspect. 11 (1) (2021) 60–68, doi:
[7] https://dx.doi.org/10.34172%2Fhpp.2021.09.
[8] H. Limami, I. Manssouri, K. Cherkaoui, M. Saadaoui, A. Khaldoun, Thermal performance of unfired lightweight clay bricks with HDPE & PET waste plastics additives (doi: https://doi.org/), J. Build. Eng. 30 (2020), 101251, https://doi.org/10.1016/j.jobe.2020.101251.
[9] M.A. Moghadam, N. Mokhtarani, B. Mokhtarani, Municipal solid waste management in Rasht City, Iran (doi: https://doi.org/), Waste Manag. 29 (1) (2009) 485–489, https://doi.org/10.1016/j.wasman.2008.02.029.
[10] R. Siddique, J. Khatib, I. Kaur, Use of recycled plastic in concrete: a review (doi: https://doi.org/), Waste Manag. 28 (10) (2008) 1835–1852, https://doi.org/10.1016/j.wasman.2007.09.011.
[11] A. Arulrajah, J. Piratheepan, M.M. Disfani, M.W. Bo, Geotechnical and geoenvironmental properties of recycled construction and demolition materials in pavement subbase applications, J. Mater. Civ. Eng. 25
[12] (8) (2013) 1077–1088.
[13] C. Albano, N. Camacho, M. Hernandez, A. Matheus, A. Gutierrez, Influence of content and particle size of per waste bottles on concrete behaviour at different w/ c ratio (doi: https://doi.org/), Waste Manag. 29 (2009) 2707–2716, https://doi.org/10.1016/j.wasman.2009.05.007.
[14] D. Foti, Preliminary analysis of concrete reinforced with waste bottles PET fibers (doi: https://doi.org/), Constr. Build. Mater. 25 (4) (2011) 1906–1915,
[15] https:// doi.org/10.1016/j.conbuildmat.2010.11.066.
[16] H.M. Adnan, A.O. Dawood, Strength behavior of reinforced concrete beam using re-cycle of PET wastes as synthetic fibers, Case Stud. Constr. Mater. 13 (2020), e00367.
[17] S. Akça¨ ozo˘ glu, C.D. Atis ¸, K. Akça¨ozo˘ glu, An investigation on the use of shredded waste PET bottles as aggregate in lightweight concrete (doi: https://doi.org/), Waste Manag. 30 (2) (2010) 285–290, https://doi.org/10.1016/j.wasman.2009.09.033
[18] Andrew, RM., 2018. Global CO2 emissions from cement production. Earth System Science Data 10, 195– 217.
[19] Camiletti, J., Soliman, AM., Nehdi, ML., 2013. Effects of nano- and micro-limestone addition on early-age properties of ultra-high-performance concrete. Materials and Structures/Materiaux et Constructions 46, 881–898.
[20] Cao, M., Ming, X., He, K., Li, L., Shen, S., 2019. Effect of macro-, micro- and nano-calcium carbonate on properties of cementitious composites A review. Materials 12.
[21] Chen, P-C., Tai, CY., Lee, KC., 1997. Morphology and growth rate of calcium carbonate crystals in a gas- liquid-solid reactive crystallizer.
[22] Cosentino, I., Restuccia, L., Ferro, GA., Tulliani, JM., 2019. Type of materials, pyrolysis conditions, carbon content and size dimensions: The parameters that influence the mechanical properties of biochar cement-based composites. Theoretical and Applied Fracture Mechanics 103, 102261.
[23] d'Amora, M., Liendo, F., Deorsola, FA., Bensaid, S., Giordani, S., 2020. Toxicological profile of calcium carbonate nanoparticles for industrial applications. Colloids and Surfaces B: Biointerfaces, 110947.
[24] Daniyal, M., Akhtar, S., Azam, A., 2019. Effect of nano-TiO2 on the properties of cementitious composites under different exposure environments. Journal of Materials Research and Technology 8, 6158–6172.



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