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Strength Properties and Electrical Resistivity of Nano-Titanium Dioxide (TiO_2) Modified Lightweight Foamed Concrete

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ABSTRACT

The need for maintaining the living environment is increasing as the economy grows and the quality of life rises. Attempting to render buildings "green" to the environment from the standpoint of civil engineering is a hot and challenging task now. The construction industry uses lightweight foamed concrete (LWFC) as a flexible building material. Contrarily, LWFC has a variety of flaws including stiffness, poor toughness, substantial porosity, crucial drying shrinkage, and minimal resistance to cracking and deformation. Although it's a sustainable solution, continuous research strives to enhance its sustainability and mechanical capabilities. Nanoparticles have excellent mechanical, thermal, and electrical capabilities that have inspired the creation of new nanocomposites with exceptional and multipurpose features. Titanium dioxide nanoparticles (TNP) have a much larger specific surface area because of nanostructures' exceptional properties. The large increase in nanoparticles will boost the role of concrete strength by improving the microstructure of the material. There is significant uncertainty regarding the process by which TNP might change the strength characteristics of LFC because the influence of TNP in LWFC was not previously explored. To better understand how TNP affects the slump flow, compressive, splitting tensile, and bending LWFC of 980 kg/m^3 density, this study will look at its effects. Six TNP weight fractions were taken into consideration: 0% (control), 1%, 2%, 3%, 4%, and 5%. Slump flow, electrical resistivity, compressive, splitting, tensile, and bending strengths were the variables investigated. In addition, the relationship between strength parameters was found. The results showed that the highest compressive, bending, and splitting tensile strengths resulted from a weight fraction of TNP of 3%.

1. Introduction

The building industry consumes a significant amount of natural resources and contributes significantly to the production of greenhouse gases and solid waste [1-5]. Despite these indicators having just achieved their maximum levels, the entity under review was responsible for the emission of 36.8 billion metric tonnes of carbon dioxide (CO_2) in the year 2022 [6-9]. Numerous public and

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commercial organizations have put policies into place aimed at reducing emissions and improving energy efficiency [10]. These efforts have led to some improvements in the decarbonization of power sources and energy investment [11]. However, it is essential to keep improving sustainability by maximizing the use of renewable and degradable materials while reducing energy usage and trash production at the same time [12-14]. With a focus on the use of concrete and its components, the construction sector confronts various sustainability difficulties [15]. The manufacture of concrete, together with its essential ingredients of binder and filler, offers considerable hazards and possible harm to human health due to an annual demand that will approach 40 billion tonnes in 2022 [16-22]. However, due to its advantageous technical characteristics, robustness, and affordability, concrete continues to be a viable building material [23-25]. It is essential to have solutions in place that reduce the negative effects connected with concrete throughout its life cycle in order to support sustainable development. These tactics could comprise using eco-friendly practices and including sustainable elements [26-30].

The construction sector has continued to thrive because of rapid expansion, but managing building projects faces increasingly difficult obstacles [31]. In urban places, atmospheric air pollution is a serious environmental problem. The main reasons for this are the continual increase in automobile units and the active building of environmentally hazardous factories inside a town's limits [32-35]. Using photocatalytic oxidation and breakdown processes, the bulk of these pollutants may be removed. Currently, photocatalysis is used extensively in international usage to filter water and air as well as to create self-cleaning surfaces and eliminate smells, among other things [36]. It has been found that adding titanium dioxide that has been changed with nano-dispersed powder to the cement composition acts as a transformer, speeding up the hardening processes and cement's hydration [37].

Since building upkeep consumes more energy in the context of the global energy crisis, energy conservation for civil structures has become one of the most important challenges [38]. By using thermal insulation materials, contemporary civil structures can use less energy throughout their lifespan by reducing heat losses through the building's outer layers. Due to its low cost, simplicity of construction, high porosity, low thermal conductivity, and fire resistance, LWFC has gained popularity as a building material for thermal insulation, among other advantages [39]. LWFC, a cellular concrete with air retained inside because of the use of an appropriate surfactant (foaming agent), has grown more popular because of its distinctive qualities, including a range of densities, the absence of coarse particles, and exceptional thermal performance [40].

LWFC may be pumped, and it typically self-levels and self-compacts. It is created using methods for mixing, moulding, maintaining, and curing. When compared to other forms of concrete, LWFC has up to 80% more pores, which has a significant impact on its insulating qualities. Combining the required foaming agents—which may be either protein- or synthetic-based—creates the LWFC cellular structure. LWFC is produced in a non-toxic manner, and when it comes into contact with fire, it doesn't release any harmful fumes. By carefully regulating the amount of foaming agents. Densities ranging from 550 kg/m^3 to 1850 kg/m^3 can be used to create LWFC [41]. A lightweight building material made of cement, water, and stable foam bubbles is called LWFC. It is produced by combining a cementitious slurry with a foaming agent, which results in the formation of a cellular structure with a lot of air space. Depending on the mix proportions, LWFC has a density that commonly ranges from 300 to 1600 kg/m^3. It contains at least 20% air gaps characterizing low density, strong thermal insulation, exceptional fire resistance, and adequate compressive strength.

Due to its benefits of being lightweight and adaptable, LWFC has garnered a lot of interest in the construction industry. The cement-based mortar with at least 20% air space is the primary characteristic of LWFC. LWFC, as a result, has a low density, high strength, and constant toughness at minimal aggregate consumption. LWFC generally has a dry density of 400 kg/m^3 to 1600 kg/m^3 and a compressive strength ranging from 1 MPa to 15 MPa [42].

Comparing LWFC to conventional concrete, the compressive strength of LWFC is often lower. Its overall structural integrity is compromised by the presence of air spaces, which prevents it from being used in applications needing higher load-bearing capacities. Its usage in some structural applications may be constrained by its low density and diminished strength. Improved interfacial characteristics and general cohesiveness in the concrete are the results of using nanoparticles to strengthen the interaction between cementitious materials and aggregates. For resolving its shortcomings and broadening its range of uses in the construction sector, the introduction of nanoparticles in LWFC seems promising. The full potential of this lightweight building material can be realized with more study in this area. The inclusion of TNP makes the current study unique in its field.

Nanotechnology has enabled the creation of custom, multifunctional cementitious composites with remarkable strength and durability properties by using nanoscale structure. Some of these materials' possible unique properties include high ductility, the ability to control fracture growth, self-healing, low electrical resistance, self-detection, and self-cleaning. Nanoparticles are those with at least one dimension less than 100 nm [43]. According to experiment findings, introducing nanoparticles improves the microstructure of self-compacting concrete [44]. Nanoparticles are presently being explored and exploited in several sectors to develop better building materials with imaginative goals because of their distinctive chemical, resilient, and physical characteristics. Nanoparticles can act as a dynamic artificial pozzolanic material to enhance the performance of cement-based products. Nanoparticle-infused concrete may have much increased compressive, bending, and tensile strengths. Nanoparticles can work as a variety of nuclei for the cement paste because of their increased reactivity as nano-fortification, increasing the hydration of cement and densifying the microstructure of concrete [45].

One of the few fields that is still in development is the use of nanoparticles in concrete. The most often utilized nanoparticles in research include carbon nanotubes, zirconium dioxide (ZrO_2), nano silica (SiO_3), aluminium oxide (Al_2O_3), iron oxide (Fe_3O4), and titanium dioxide (TiO_2) [46]. According to experimental findings, adding nanoparticles to concrete significantly reduces permeability, while also decreasing compressive strength in select combinations and boosting bending strength in the majority of the situations under study [47]. The inclusion of nanoparticles may smooth out the grains, densify the microstructure of the nanocomposites, and raise the hardness of the materials. By densifying the microstructure, nanoparticles may significantly enhance the hardness of composite materials.

The quicker concrete hydrates, the quicker it becomes stronger. As particle size is reduced, the same materials react differently [48]. According to studies, adding chemically inert nanoparticles like magnetite (Fe_3O_4) and titanium dioxide (TiO_2) speeds up early hydration by providing more nucleation sites, greater rate peaks, and more overall hydration heat [49]. Nanoparticles are in charge of atomic-level issues, which deal with atoms smaller than 100 nm [50,51]. As a photocatalyst, TNP could accelerate light-induced redox processes and help break down airborne contaminants like nitrogen oxides. TNP may effectively break down dangerous gases and purify the air while improving the strength properties of concrete, such as compressive strength, bending strength, and splitting tensile strength [52]. This study focuses on the various TNP addition percentages to LWFC while considering the advantages of doing so. As a result, experimental research into the effects of LWFC's varied strength strengths and electrical resistivity were conducted, and applications of LWFC reinforced by TNP are assessed.

2. Methodology

This section talks about the components required to make LWFC in addition to the mix proportions and laboratory test procedures. Following is a thorough description of material preparation. The mix ratios, mixing methods, and experimental plans for the LWFC samples reinforced with TNP were established after that. This research sought to determine how TNP affected the strength properties of LWFC at six different weight fractions., especially 0% (control), 1%, 2%, 3%, 4%, and 5%. A dry density LWFC of 980 kg/m^3 was created. Because they are used as semi structural elements in the construction of buildings and can benefit from TNP reinforcement, LWFC with a medium density were taken into consideration in this study. Investigated were strength characteristics. Compressive strength, split tensile test, and bending strength test are three strength properties that have been investigated. The link between compressive strength and bending strength, split tensile strength and bending strength, and split tensile strength was also computed to ascertain how closely related these attributes are to one another.

2.1 Constituent Materials

The fabrication and testing of lightweight LWFC with varied TNP weight fractions ranging from 0% to 5% are the main objectives of this work. For comparison, a control LWFC was also created. To manufacture LWFC, Ordinary Portland Cement (OPC) (CEM1 52.5 R) was used as the cementitious ingredient. OPC CEM-I, sold commercially under the brand Blue Lion, was the cement used in the study to create the LWFC mix. The 2.59 specific gravity fine river sand was purchased commercially from one of the best quarries. The sand complied with ASTM C33-03 requirements. Figure 1 shows the sand sieve analysis result in line with ASTM C33-03 [53].

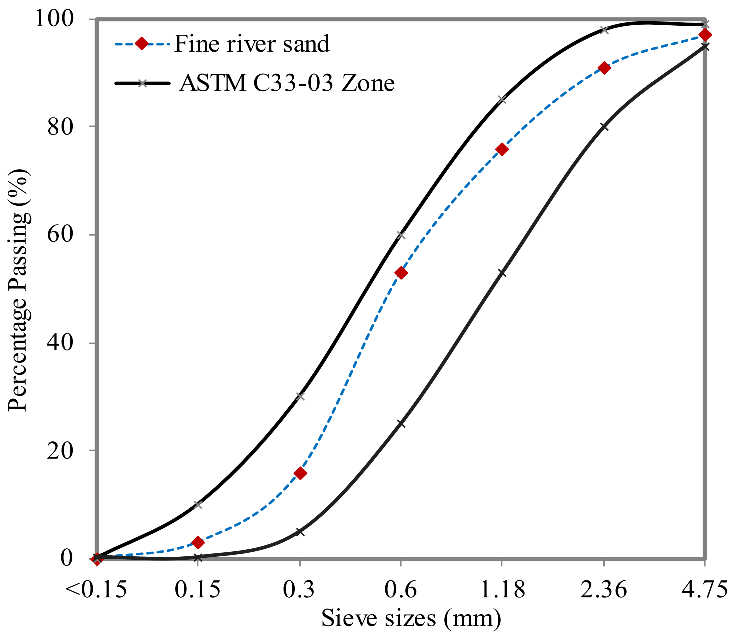

Fig. 1. Sand sieve analysis result in line with ASTM C33-03

In accordance with BS-3148, pure drinking water from the tap was utilized in this experiment. A commercial protein-based foaming agent that could provide a density of 68 ± 15 kg/m^3 after being diluted with water in a ratio of 1:30 is used. The homogenous foam dispersion in cement paste required high-speed shearing of the foaming agent to create the foam, which was necessary to create a consistent pore structure. Titanium dioxide is chosen to be used in LWFC in this experiment. TNP has several advantages when used as a nanoparticle in cement-based products. Titanium dioxide (TiO_2), a remarkable photocatalytic material, bestows biocidal, self-cleaning, and smog-abating properties when added to cement-based products. TiO_2 affects both the hydration process and the development of the internal structure of cement. TiO_2 increases the compressive strength, bending strength, and splitting tensile strength of the LWFC.

In addition, TNP is a photocatalyst, which means that when exposed to light, it may start chemical processes. TNP can aid in the breakdown of organic pollutants in LWFC, including airborne contaminants and volatile organic compounds (VOCs). This photocatalytic process can help clean the air and lessen environmental pollution. Due to the improved adhesion and better connection, they create with the cementitious matrix, these cutting-edge TNP are ideal for LWFC applications. Additionally, TNP can enhance the thermal characteristics of LWFC. It reflects sun radiation well, which lessens the amount of heat that the concrete absorbs. Better insulation and energy efficiency in buildings may result from this, which may save heating and cooling expenses. The TNP used in this work is depicted in Figure 2. Table 1 shows the mix proportion of the LWFC; the TNP was added to the LWFC with varied weight fractions of 0%, 1%, 2%, 3%, 4%, and 5%. TNP used in this investigation was more than 99.5% pure and ranged in size from 55 to 75 nm. Six different TD weight fractions (0%, 1%, 2%, 3%, 4%, and 5%) were used.

Fig. 2. Nano-titanium dioxide utilized in this investigation

2.2 Mix Design

This study produced and examined a target dry density of 980 kg/m^3. Constant cement-to-filler and water-to-cement ratios of 1:1.5 are used. There were developed six different LWFC mixes. Table 1 displays the proportion of the LWFC mix. Figure 3 shows the LWFC mixing process.

Table 1
Mix proportion of LWFC

Mix reference	Target density (kg/m^3)	Wet density (kg/m^3)	TD weight fraction (%)	TD (kg/m^3)	Binder (kg/m^3)	Filler (kg/m^3)	Water (kg/m^3)	Foam (kg/m^3)
FC-TD0	980	1115	0.0	0.0	361	542	181	31
FC-TD1	980	1115	1.0	11.2	361	542	181	31
FC-TD2	980	1115	2.0	22.3	361	542	181	31
FC-TD3	980	1115	3.0	33.5	361	542	181	31
FC-TD4	980	1115	4.0	44.6	361	542	181	31
FC-TD5	980	1115	5.0	55.8	361	542	181	31

Fig. 3. LWFC mixing process

2.3 Experimental Setup

In this research, the strength properties of LWFC with the addition of TNP were examined. The parameters evaluated were slump flow, compressive strength, four-point bending strength and split tensile strength.

2.3.1 Slump test

The workability of LWFC was evaluated using the slump test. The spread ability test was governed by the specifications outlined in ASTM C 230-97 [54]. The slump properties of several LWFC mixes were evaluated using an open-ended cylinder with a diameter of 107 mm and a height of 400 mm (Figure 4(a)). After the concrete was poured into the cylinder without being compacted, it was lifted in a vertical position, and the average of two diameters perpendicular to each other was calculated. Throughout the production process, the LWFC mixes' plastic and ultimate dry densities were also measured.

2.3.2 Electrical resistivity test

The measurement of the bulk resistivity of LWFC was performed through the implementation of an electrical resistivity test, following the guidelines outlined in the ASTM C1760 standard [55]. The characteristic of electrical resistivity is a material property that is utilized in various applications, one of which is the assessment of the initial properties of LWFC.

2.3.3 Axial compression test

A compression test was performed on a 100 x 100 x 100 mm cube in accordance with BS-EN12390-3, as illustrated in Figure 4(b) [56]. The results represent the average of three samples in each case. An axial compressive force with a constant speed of 0.025 mm/s was applied to the LWFC cubic samples. The LWFC compressive strength is calculated using the formula below.

$$\text{Compressive strength } (F) = P/A \text{ (MPa)} \tag{1}$$

where P = maximum load on the LWFC sample (N); A = cross-sectional area of the sample resisting the load (mm^2).

2.3.4 Four-point bending test

Only the average data were recorded during the three-way bending strength testing for LWFCs, which was done in accordance with BS EN 12390-5 and employed a prism specimen of 100 x 100 x 500 mm [57]. The testing was done with center-point loading. A focused force, P, equal to a stroke at a constant speed of 0.085 mm/s, was applied at the midpoint of the span. Throughout this period, the force that created the fracture was concurrently visible. The setup for the four-point bending test is shown in Figure 4(c). The bending strength of the LWFC prism specimen is determined using the following equation.

$$\text{Bending Strength } (F) = 3PL/2bd^2 \tag{2}$$

where;
P = Failure/maximum Load (N)
L = Effective span (mm)
b = breadth of the specimen (mm)
d = depth of the specimen (mm)

2.3.5 Split tensile test

In this study, the splitting tensile test was employed in compliance with BS1881-122 as per shown in Figure 4(d) [58]. A Cylinder of diameter 75mm and height 100mm was used as a test specimen. The following equation is used to establish the strength.

$$\text{Splitting Tensile Strength} = 2F/\Pi DL \tag{3}$$

where,
F = applied force on the specimen (N)

D = diameter of the specimen (mm)
L = length of the specimen (mm)

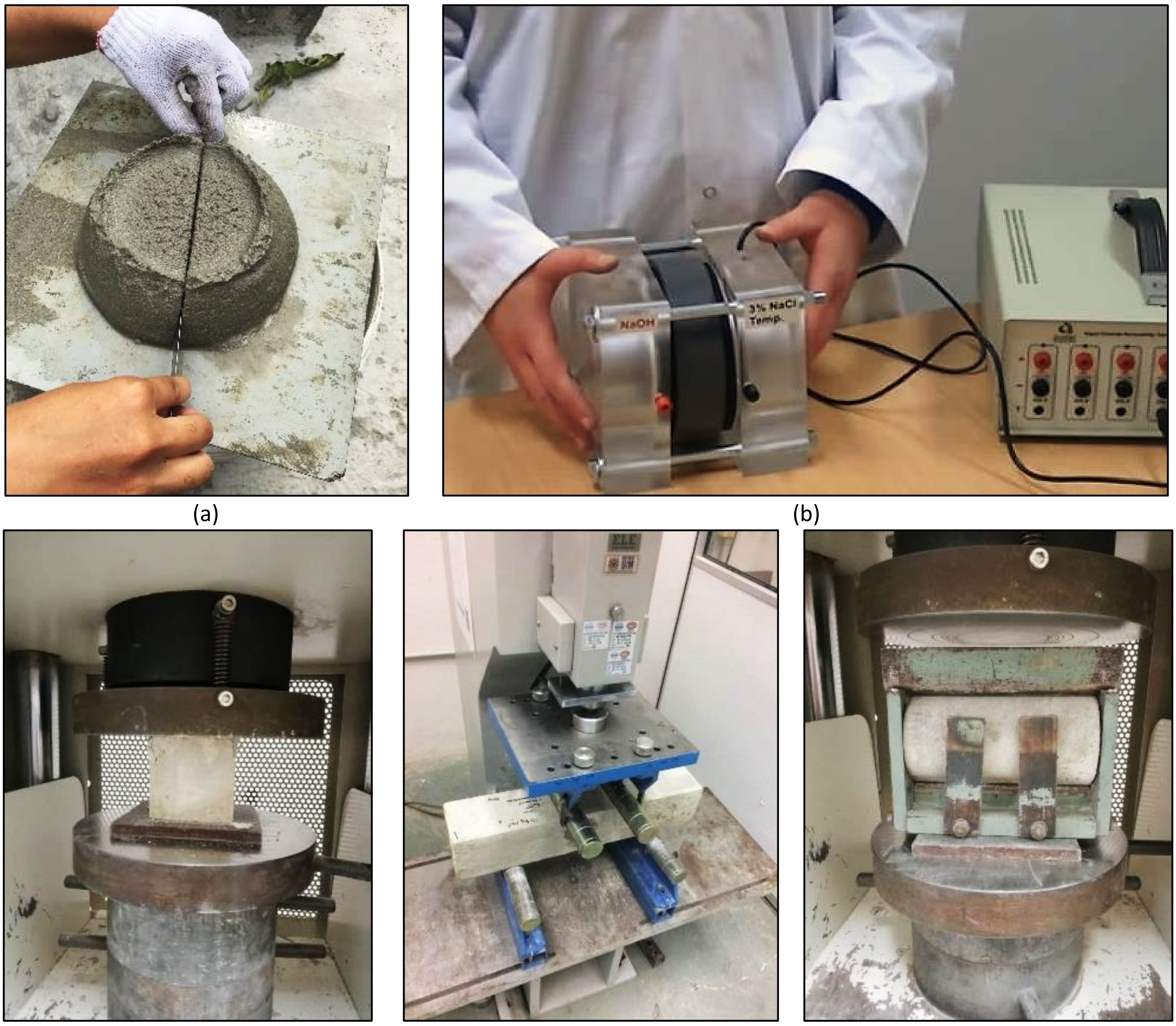

Fig. 4. Tests conducted (a) slump test; (b) compression test; (c) four-point bending test; (d) split tensile test

3. Results and Discussions

3.1 Slump Test

Figure 5 depicts the slump flow of LWFC mixtures with different weight percentages of TNP. It is clear that when the water-cement ratio for the mix was kept at 0.45, the slump flow reduced as TNP weight fractions increased. The control LWFC's slump flow (without TNP) reached a slump of 248 mm. While the lowest slump values, 234 mm, was found in the LWFC combinations that had 5% TNP added. This is mostly due to the greater weight fraction of TNP having an impact on the mixture's viscosity and flow characteristics. Lower TNP weight fractions may cause the particles to have less of an impact on the rheological characteristics, resulting in a mixture that slumps more due to decreased internal friction and better flowability.

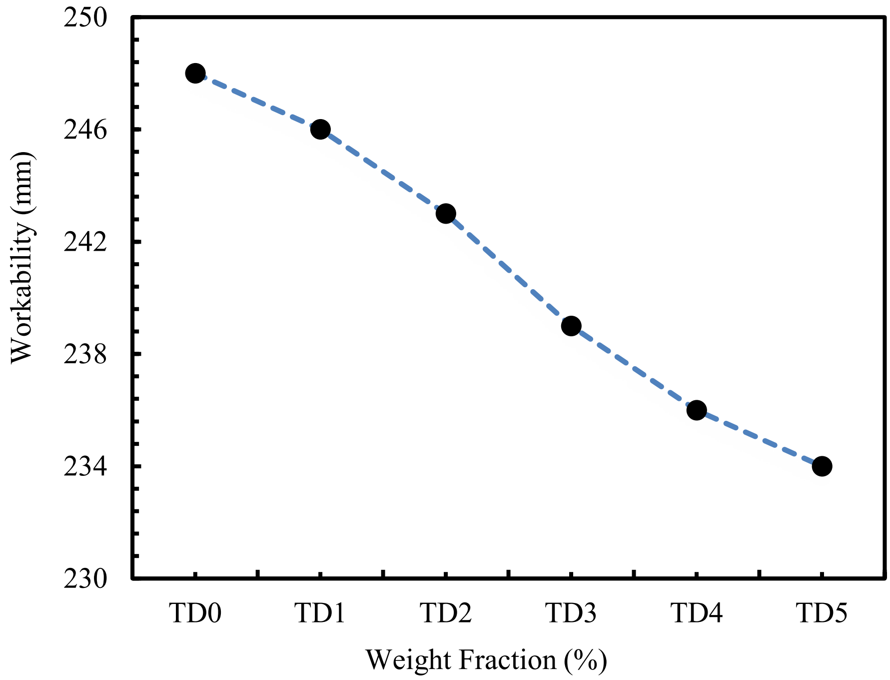

Fig. 5. Slump flow of LWFC with different weight fractions of TNP

3.2 Electric Resistivity

The results of the electrical resistivity analysis performed on LWFC samples containing different amounts of TNP incorporation are presented in Figure 6. The mix TD30 exhibited superior electrical resistivity in comparison to the other mixes. The control mixture (TD0) exhibited the highest level of electrical resistivity. It is imperative to note that the 28-day electrical resistivity of TD40 exhibits a higher value compared to that of TD30. When comparing the electrical resistivity of TD50 and TD40, it can be observed that TD50 demonstrates a higher value over a 28-day period. The observed phenomenon can be ascribed to a greater degree of discontinuity in the pore structure of TD40 in comparison to TD30. It is noteworthy to acknowledge that the prevalence of defects in mixtures containing TNP is comparatively greater than that of TD50. The incorporation of TNP within a cementitious system promotes the formation of secondary crystals by reacting with the pre-existing portlandite. This procedure facilitates the improvement of the microstructure. The aforementioned crystals possess the capacity to partition larger void spaces into smaller compartments. As a result, it is likely that a larger number of smaller, disconnected pores are created. The assessment of electrical resistivity provides an indirect means of evaluating the ability of LWFC to hinder the infiltration and subsequent migration of detrimental chemical ions, particularly chloride, and sulphate.

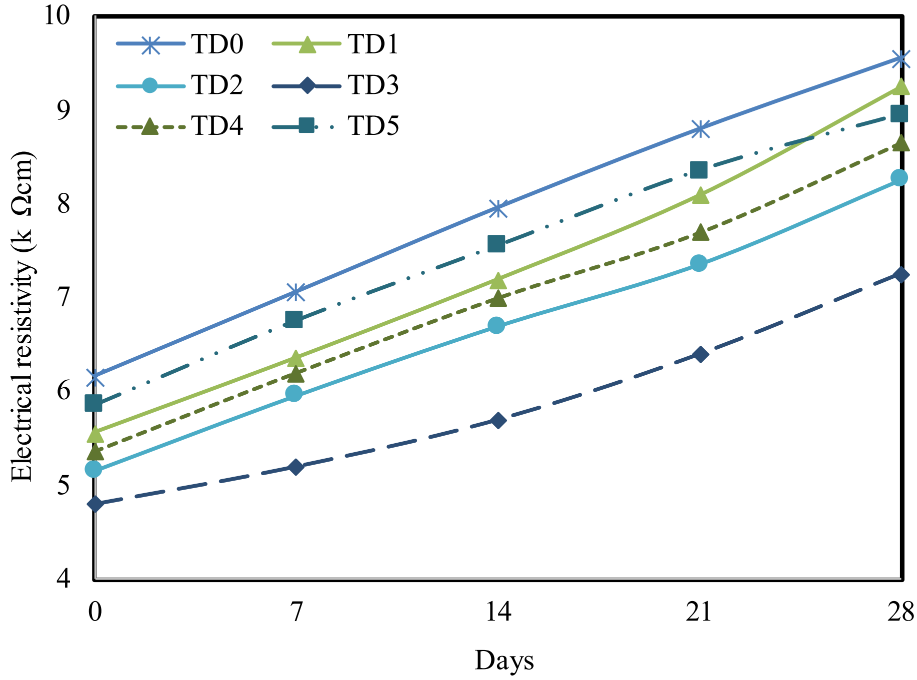

Fig. 6. Electrical resistivity of LWFC with different weight fractions of TNP

3.3 Compressive Strength

The nanoparticles fill in the gaps and increase the material's packing density by acting as fillers. Increased interparticle contact and greater load transmission may occur from this improved packing, increasing compressive strength. The compressive strengths of each LWFC specimen at the ages of 7, 28, and 56 days are shown in Figure 7. By comparison to TD0 (control sample), Figure 7 amplifies the compressive strength for entire mixtures and testing ages. This is demonstrated clearly. The addition of 3% TNP in the LWFC mix (TD3) resulted in the best compressive strength, which had been enhanced by 3.79 N/mm^2, 4.5 N/mm^2, and 5.2 N/mm^2 at curing ages of 7, 28, and 56 days, respectively, in comparison to the control sample (TD0). The percentages of enhancement were 61.9%, 61.8% and 67.7% respectively in comparison with the TD0 (control sample). This is mostly due to the ability of TNP to improve the compressive strength of materials made of cement.

The influence of hydration acceleration and the ability to modify pores both contribute to nano-TNP's ability to increase cementitious material's compressive strength. Nano-TNP decreases the contact angles of the cement-based material in conjunction with its pore-refining effect, resulting in less water loss during drying. The reduced water loss brought on by the impacts of nano-TiO_2 on pore-refining and paste-hydrophilicity-increasing effects reduces the drying shrinkage of cement-based materials [59]. According to the test results, adding more TNP can boost compressive strength while maintaining the material's performance, especially at lower water-to-solids ratios. Particle clumping and agglomeration are caused by the non-uniform dispersion of the particles when TNP concentrations more than 3% are added to the LWFC mix. Consequently, this process causes the LWFC's compressive strength to decrease. The size and distribution of TNP can also have an impact on the increase in compressive strength. A more homogenous structure can be promoted by smaller particle sizes and uniform distribution throughout the matrix, which can lower the likelihood of flaws and increase overall strength. The hydration and reaction processes of cement can be affected by the inclusion of TNP. The nanoparticles may speed up and promote the formation of calcium silicate hydrate (C-S-H) gel, which is what gives cementitious materials their strength. This happened as a result of insufficiently distributed nanoparticles in the LWFC matrix and a decrease in the concentration of crystalline $Ca(OH)_2$ required for the formation of the C-SH gel. In comparison to increasing the titanium dioxide concentration in LWFC, adding nano-TNP particles reduced the workability of fresh concrete after 3% of weight fraction of TNP.

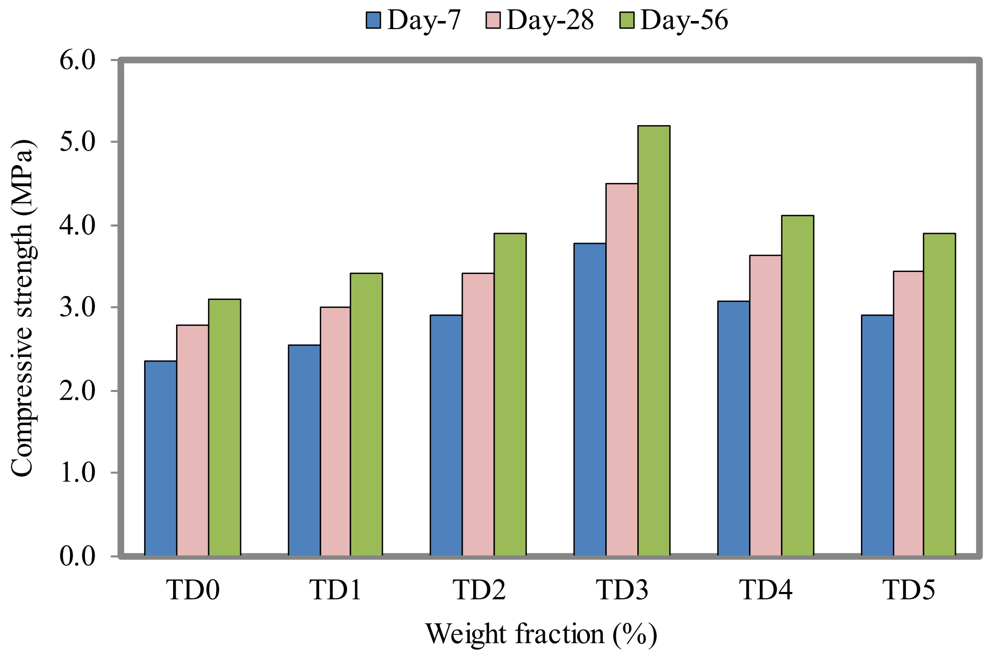

Fig. 7. Influence of varying weight fractions of nano-titanium dioxide on axial compressive strength of LWFC

3.4 Bending Strength

Figure 8 provides evidence of the bending strengths of each LWFC specimen at the ages of 7, 28, and 56 days. Figure 8 demonstrates that the addition of TNP to LWFC enhanced the bending strength for all mixes and testing ages in comparison to mix C (the control sample). The addition of 3% TNP in the LWFC mix allowed for the achievement of the ideal bending strength and resulted in improvements of 60.42%, 59.6%, and 63.5% in comparison to the control sample at curing ages of 7, 28, and 56 days, respectively. The faster utilization of crystalline $Ca(OH)_2$, which spontaneously forms during cement hydration and especially at a young age due to TNP's high reactivity, was the source of the increased bending strength reached with the addition of TNP. It has been noted that TNP enhances the microstructure of LWFC by decreasing porosity and increasing density, which improves bending strength.

He *et al.,* [60] studied that the micro-filling action of nanoparticles makes the integration of nano-TNP advantageous for strengthening concrete. The strongest material in terms of material strength had a cement nano-TNP level of up to 3%. In this investigation, it was clear how TNP affected the mortars' strength. It is evident that mortar strength increased quickly after TNP concentration reached 2%, with bending strength showing the greatest gain. Ettringite and C-S-H gel content directly influence the cement mortar's strength, and nanoparticles make it easier for the cement to hydrate and produce more hydration products. The enhanced surface area turns out to be a great place for hydration products in addition to their filler property to fill the gaps in C-S-H gels since nanoparticles are known to have a large surface area to volume ratio [61].

The bending strength of LWFC increased with an increase in the TNP weight fraction of up to 3%, as was described in the part before because of the excessive aggregation of TNP at greater concentrations is one possible cause. Agglomeration can result in insufficient stress transmission and decreased overall strength within the concrete matrix by preventing efficient dispersion. The greater porosity of the concrete with higher TNP content may also be a contributing factor. Excessive TNP may fill holes or air pockets inside the concrete, weakening the substance's integrity and reducing bending strength.

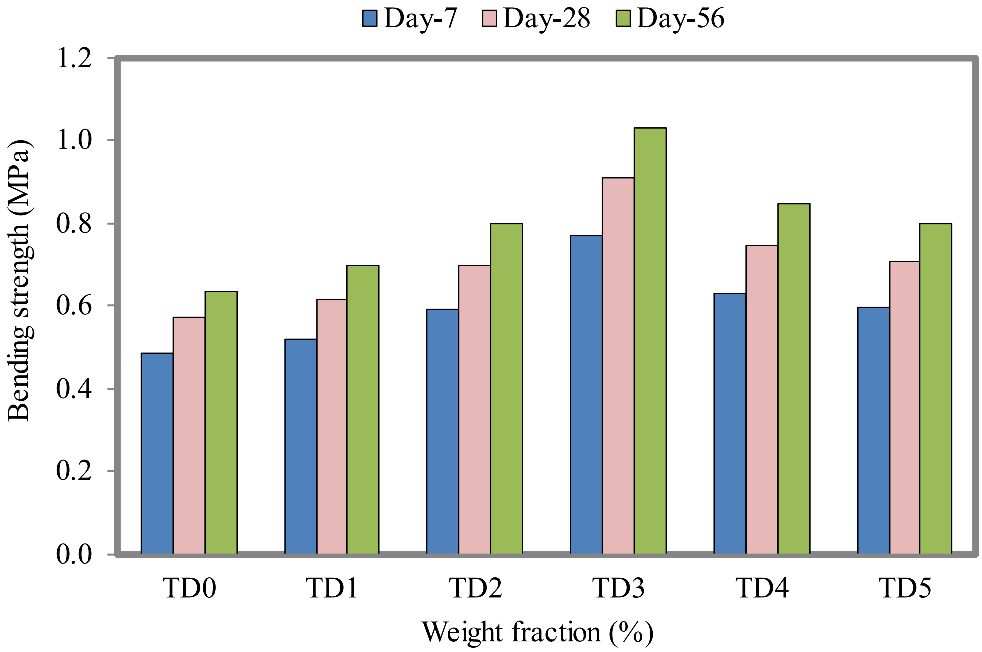

Fig. 8. Influence of varying weight fractions of nano-titanium dioxide on bending strength of LWFC

3.5 Split Tensile Strength

Figure 9 displays the splitting tensile strengths of each LWFC at 7, 28, and 56 days. In contrast to control LWFC samples, it was discovered that the splitting tensile strength of LWFC increased with increased weight fractions of TNP, as shown in Figure 9. This finding suggests that the presence of nanoparticles in the cementitious matrix of LWFC plays a critical role in accelerating the process of hydration. These atoms speed up the hydration process due to their high activity and volatility. The appropriate amount of splitting tensile strength was reached with 3% TNP added to the LWFC mixture. At curing ages of 7, 28, and 56 days, respectively, this led to improvements of 70%, 74.3%, and 76.9% in contrast to the control sample.

When TNP is added as an addition to LWFC, it interacts at the molecular level with the foam matrix, changing the concrete's overall structure and qualities. TNP may strengthen the material by encouraging improved particle dispersion and foaming site nucleation at low concentrations, as seen in Figure 9. However, at concentrations more than 3% weight fraction, it may cluster or have undesirable interactions with other components, reducing the impact. The surface area available for the bonding and densification of the concrete may be reduced by higher TNP concentrations due to particle agglomeration [62]. This may lead to less effective particle packing and weaker interparticle bonds, which would eventually result in reduced strength.

Weaker phases or microstructural flaws may emerge because of improper curing or changed hydration kinetics. TNP may lead to excessive porosity in the concrete matrix as its concentration rises beyond a certain limit [63]. Although the cellular structure of LWFC is intrinsic, an excessive amount of TNP may cause greater cavities or an uneven distribution of particles, which would weaken the material. In some circumstances, the chemical compatibility of TNP particles with the components of LWFC may be compromised, causing undesired reactions or phase shifts that reduce the material's tensile strength.

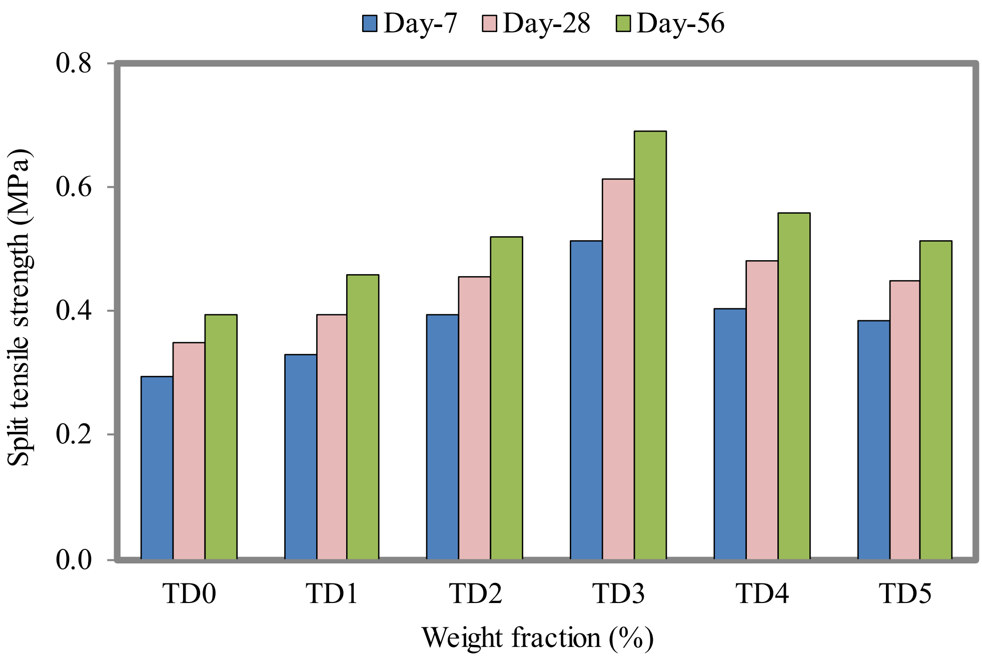

Fig. 9. Influence of varying weight fractions of nano-titanium dioxide on split tensile strength of LWFC

3.6 Correlation between Compressive and Bending Strengths

Figure 10 shows the potential relationship between the bending and compressive strengths of LWFC when TNP is present. The relationship between compressive and bending strengths was displayed. The distribution of data, as shown in Figure 10, supports the existence of a reasonable relationship between compressive strength and bending. With a significant regression value (0.99), a strong linear association is clearly visible. The bending strength for the control specimen (plain LWFC) was around 20.51% of the LWFC's compressive strength. With the optimal weight fraction of 3% TNP, the bending strength averaged 20.11% of the compressive strength. The decrease in strength can be attributed to inadequate dispersion or aggregation of particles, resulting in the formation of weaker zones. TNP has an impact on the LWFC's pore structure. Compressive and bending strengths are influenced by the material's total density and microstructure, which means that changes in pore size distribution and porosity can influence both of these properties [64].

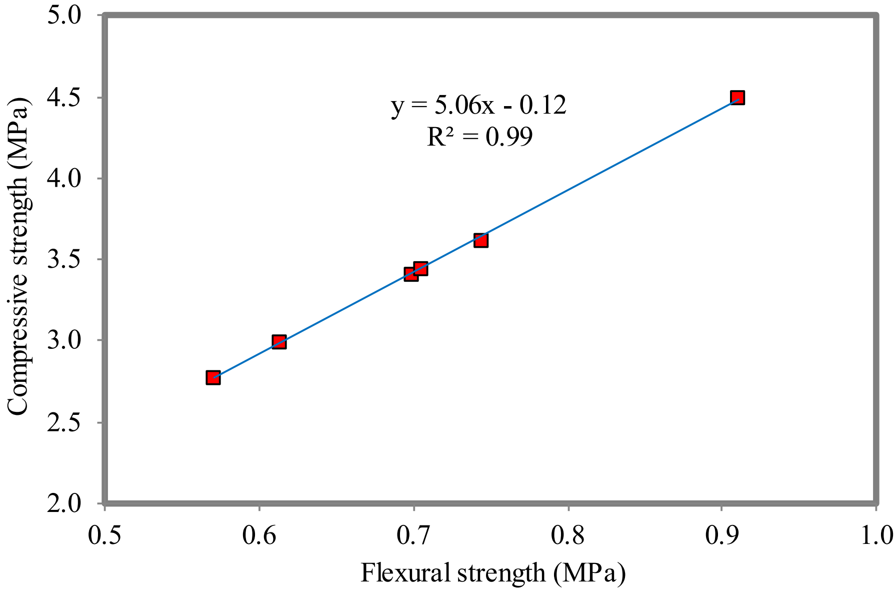

Fig. 10. Correlation between compressive and bending strengths of LWFC with different weight fractions of nano-titanium dioxide

3.7 Correlation between Compressive and Split Tensile Strengths

The relationship between the compressive and splitting tensile strengths of LWFC is seen in Figure 11. With an R-squared value in the range of 0.99, it clearly shown that a direct growing pattern can be seen in splitting tensile strength vs compressive strength. The relationship indicates that when compressive strength grows, splitting tensile strength also does. TNP have an impact on the LWFC 's pore structure. As both compressive and split tensile strengths are influenced by the material's overall density and microstructure, changes in pore size distribution and porosity may influence both of these properties. Hydration products are dispersed and encapsulated in the TNP as soon as it begins. Due to their great reactivity, TNPs present in the LWFC matrix can also aid in stimulating cement hydration.

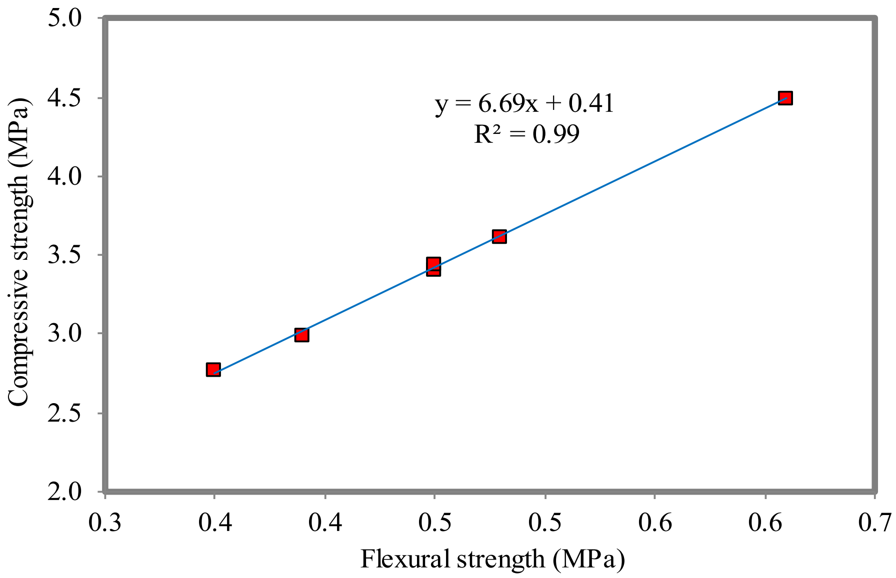

Fig. 11. Correlation between compressive and split tensile strengths of LWFC with different weight fractions of nano-titanium dioxide

3.8 Correlation between Split Tensile and Bending Strengths

The correlation between the splitting tensile and bending strengths of LWFC is seen in Figure 12. Splitting tensile strength vs. compressive strength clearly demonstrated a direct increasing trend with an R-squared value in the region of 0.99. According to the connection, splitting tensile strength likewise increases as bending strength does. The LWFC mix's other constituents and TNP may interact to form new compounds that have higher split and bending tensile strengths. Furthermore, the TNP's presence in the LWFC matrix enabled consistent TNP nanoparticle dispersion throughout the concrete matrix [65].

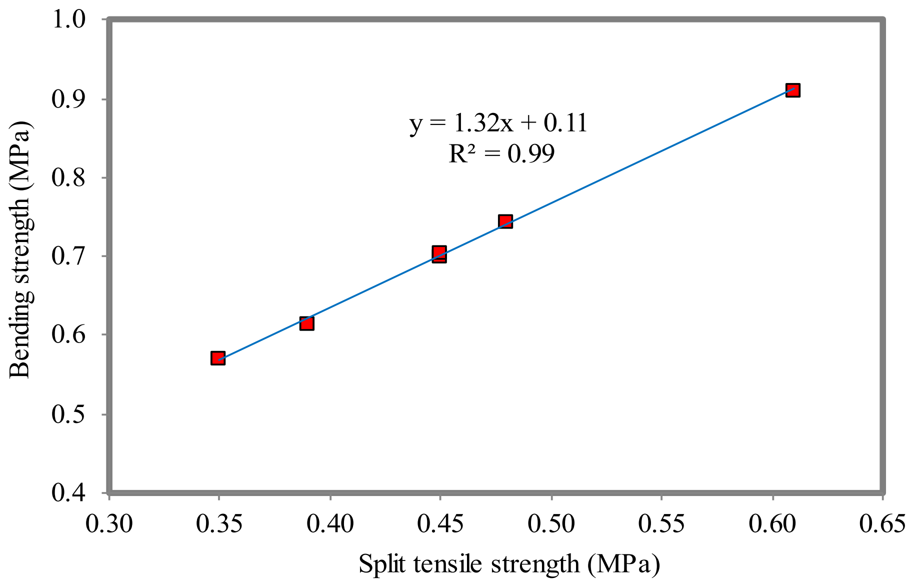

Fig. 12. Correlation between bending and split tensile strengths of LWFC with different weight fractions of nano-titanium dioxide

4. Conclusions

LWFC was mixed with 0–5% TNPs by weight fraction in this study. Assessed were strength properties as splitting tensile strength, compressive strength, and bending strength. The research findings lead to the following conclusions:

i. Because of its unique qualities, which include the ability to decrease the porosity of the cementitious matrix, TNP has a great potential to be combined with LWFC to improve strength performance. This results in a microstructure that is denser and more compact, which helps to boost the material's strength and durability. With specimen 3% TiO_2, the best outcomes for these three strength characteristics were reached.
ii. The specimen LWFC with 3% of TNP that provided an improvement of 61.9%, 61.8%, and 67.7% at curing ages 7, 28, and 56 days, respectively, over the control specimen was found to have the best compressive strength. The homogeneous dispersion of TNP throughout the concrete matrix, which is essential for enhancing strength qualities, was achieved with the help of TNP.
iii. In comparison to the control sample, the specimen LWFC25 shown improvements of 60.3%, 55.2%, and 53.3% at curing ages of 7, 28, and 56 days, respectively. The higher bending strength obtained with the addition of TNP was caused by the quicker utilisation

of calcium hydroxide, which rapidly appears during the hydration of cement, especially at an early age due of the high reactivity of TNP. Specimen with 3% TNP, which improved by 60.42%, 59.6%, and 63.5% at curing ages 7, 28, and 56 days, respectively, in contrast to the control specimen, provided the optimal bending strength. The hydrated cementitious matrix's voids are permeated by the exceptionally low surface area, which accumulates to a higher density and, as a result, resulting in a higher splitting tensile strength.

iv. Chemical interactions with other ingredients in the LWFC mix, such as cement and additives, might be the cause of the decrease in compressive, bending, and cracking tensile strengths with a further increase in the TNP weight fractions from 3% to 5% TNP. The observed drop in bending strength may be caused by interactions that give rise to compounds with worse strength properties.

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