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Investigating The Effect of Nanomaterials and Texture Type on The Anti-Inflammatory Properties of Finished Fabrics

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Abstract

This study investigates the application of nano strontium titanate ($SrTiO_3$) and nano zinc titanate ($ZnTiO_3$) in textile finishing to enhance antibacterial, anti-inflammatory, and UV-protective properties of fabrics. Both woven cotton and electro spun nonwoven fabrics were treated with these nano powders and characterized for their physical and biological performance. The treated textiles demonstrated remarkable bactericidal activity, with higher effectiveness against Escherichia coli compared to Bacillus cereus, attributed to differences in bacterial cell wall thickness. Moreover, the fabrics exhibited significant anti-inflammatory properties, reducing carrageenan-induced edema in animal models. Durability tests revealed that the antimicrobial effect of both nano powders was maintained above 93% even after 15 washing cycles, confirming their stability and long-term applicability. In addition, UV-blocking and photocatalytic performance were notably improved, particularly in fabrics treated with strontium titanate. These findings highlight the potential of $SrTiO_3$ and $ZnTiO_3$ nanoparticles as multifunctional agents in the development of advanced textiles for medical, protective, and outdoor applications.

Keywords: Antibacterial textiles; Anti-inflammatory fabrics; Durable textile finishing.

1. Introduction

In the dynamic field of textile manufacturing, continuous efforts are being made to discover advanced approaches that improve the strength and longevity of fabrics. Among the nanomaterials recently highlighted, strontium titanate and zinc titanate have shown considerable promise. These nano powders not only enhance fabric strength and abrasion resistance but also exhibit valuable characteristics such as antibacterial activity, self-

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cleaning ability, and ultraviolet (UV) shielding. Such features are particularly vital in industries where hygiene maintenance and prevention of bacterial spread are critical [1-4].

Strontium titanate ($SrTiO_3$) and zinc titanate ($ZnTiO_3$) are both perovskite-structured compounds with outstanding mechanical and electrical properties. When utilized in textile finishing, these nanoparticles can significantly boost fabric performance. Their nanoscale dimensions and high surface area promote stronger adhesion and deeper penetration into fibers, thereby improving the overall efficiency of the treatment [5,6].

Strontium titanate is recognized for its high dielectric constant and piezoelectric characteristics. Applied as a textile coating, it creates a thin and uniform surface layer that reinforces the structural integrity of fabrics. Additionally, strontium titanate nanoparticles can impart anti-static properties, prevent static charge buildup and reduce the risk of discomfort or electrostatic discharge damage [7].

Conversely, zinc titanate demonstrates strong photocatalytic activity and effective UV absorption capability. Integrating zinc titanate nanoparticles into fabric finishes enhances resistance to UV-related degradation, ultimately extending fabric durability. This property makes such treated textiles especially useful in outdoor environments where sunlight exposure is frequent [8].

A study published in the *Journal of Natural Fibers* [9] investigated the application of nano-strontium titanate on cork webs for UV protection and mechanical reinforcement. Results revealed significant improvements in UV-blocking capacity and tensile strength, attributed to the improved interaction and bonding between nanoparticles and the fabric matrix.

Research conducted by Zohoori et al. [10,11] further examined the integration of strontium titanate and titanium dioxide nanoparticles into cotton textiles. Their findings indicated that the modified fabrics exhibited enhanced self-cleaning behavior compared to untreated samples.

In the biomedical domain, particularly oncology, researchers have assessed the impact of zinc titanate-modified fabrics on cancer cell inhibition. A study reported in the *International Journal of Nanomedicine* [12] analyzed the cytotoxicity of zinc titanate-treated textiles and found selective apoptosis in cancer cells, while healthy cells remained unaffected. This targeted action suggests potential for therapeutic textile development, offering both comfort and functional benefits for cancer patients.

Moreover, investigations into the durability of zinc titanate coatings on fabrics have been carried out. Samples subjected to repeated washing and abrasion tests maintained antimicrobial and cytotoxic properties, indicating that the treatment is both practical and long-lasting [13-15].

Further research has also assessed the persistence of nanomaterial-based finishes on textiles under conditions such as washing, mechanical stress, and abrasion. Findings confirmed that the anti-inflammatory effectiveness of nanoparticles remained intact even after multiple wash cycles, reinforcing their applicability and durability in textile finishing processes [16-19, 25].

In this study, we introduce a novel approach by incorporating nano strontium titanate ($SrTiO_3$) and nano zinc titanate ($ZnTiO_3$) into both woven cotton and electrospun nonwoven fabrics to simultaneously enhance their antibacterial and anti-inflammatory properties. While previous research has primarily focused on the individual application of conventional nanoparticles such as ZnO or TiO_2, this work uniquely explores the multifunctional performance of titanate-based nanomaterials in textile finishing. Furthermore, the study provides a comprehensive evaluation of durability after repeated washing cycles, alongside biological assessments including antibacterial efficacy against both Gram-positive and Gram-negative bacteria and anti-inflammatory response in vivo. This integrated approach highlights the potential of titanate nanoparticles as next-generation agents for developing advanced medical and protective textiles with long-lasting multifunctionality.

2. Materials and Methods

Nano-sized strontium titanate powder (CAS No. 12060-59-2) with a molecular weight of 183.49 g/mol, particle size less than 100 nm, and a density of 4.81 g/mL was obtained from Sigma-Aldrich. Similarly, zinc titanate nano powder with a molecular weight of 161.26 g/mol and particle size below 100 nm was also sourced from Sigma-Aldrich. The textile substrate used in this study was 100% bleached cotton fabric, characterized by a warp density of 22 yarns/cm, a weft density of 18 yarns/cm, and a fabric weight of 119.4 g/m^2, supplied by Yazd-Baff Company. Bio-based succinic acid (CAS No. 110-15-6) was employed as a cross-linking agent, while sodium hypophosphite and Schweizer's reagent were procured from Merck. An Euronda ultrasonic bath (model Eurosonic 4D, 350 W, 50/60 Hz, Italy) was utilized during the experimental procedures. Tensile strength measurements were carried out using a tabletop uniaxial testing system (INSTRON 3345). Abrasion resistance was evaluated following ASTM D-3884-09 using a double-head rotary platform method. The morphological characteristics of the treated samples were examined through scanning electron microscopy (SEM, MIRA3-TESCAN), after coating the specimens with a thin layer of gold.

As presented in Table 1, two types of fabrics incorporating different concentrations of nanomaterials were prepared. In samples A and B, the woven cotton fabric (warp/weft) was finished separately with nano-strontium titanate and nano-zinc titanate. In contrast, samples C and D consisted of electrospun nonwoven fabrics treated with the same nanomaterials.

The finishing procedure for samples A and B was carried out as follows: initially, the cotton fabrics were washed with distilled water at 85 °C for 60 minutes. After washing, the fabrics were immersed in a solution containing sodium hypophosphite (catalyst) and succinic acid (cross-linking agent) for 60 minutes at a weight ratio of 4:6. Subsequently, the treated fabrics were dried at 80 °C for 4 minutes, followed by immediate curing at 180 °C for 2 minutes. During this stage, separate suspensions of nano-strontium titanate and nano-zinc titanate were prepared and sonicated for 30 minutes in an ultrasonic bath. The cured fabrics were then immersed in these suspensions and subjected to ultrasonic treatment for another 30 minutes at 80 °C. To ensure fixation of the nanoparticles, the fabrics were heated in an oven at 100 °C for 3 minutes, followed by ultrasonic washing for 10 minutes to remove any unbound nanoparticles. Samples A and B were obtained using this method.

For samples C and D, the electrospinning technique was applied. In this process, 100% cellulose was dissolved in Schweizer's reagent and mixed with 1.5% nanomaterials before sonication. The prepared solution was loaded into a syringe and electrospun under the following conditions: a nozzle-to-collector distance of 15 cm, drum speed of 135 rpm, feeding rate of 0.5 mL/h, applied voltage of 20 kV, and a traverse speed of 0.4 m/min. This procedure resulted in the formation of nonwoven fabrics.

The antibacterial activity of the treated fabrics was evaluated according to the AATCC 100-2004 standard against two bacterial strains: Bacillus cereus (Gram-positive) and Escherichia coli (Gram-negative).

Table 1. Specification of samples

Sample Code	Texture Type	$SrTiO_3$ (%)	$ZnTiO_3$ (%)
A	Warp/Weft	1.5	0
B	Warp/Weft	0	1.5
C	Nonwoven	1.5	0
D	Nonwoven	0	1.5

3. Results and Discussion

3.1. Antibacterial Analysis

Escherichia coli and Bacillus cereus are two common bacterial strains, representing Gram-negative and Gram-positive types, respectively. *Bacillus cereus* is a rod-shaped microorganism commonly present in soil and food, and it is known to cause illnesses such as nausea, diarrhea, and vomiting syndrome [20]. In contrast, the Gram-negative bacterium *E. coli* can lead to a wide range of infections, including gastroenteritis, urinary tract infections, neonatal meningitis, hemorrhagic colitis, and Crohn's disease [21].

Nano zinc oxide (ZnO) is considered biocompatible, making it suitable for applications in pharmaceutical and medical textiles [22]. Moreover, ZnO nanoparticles exhibit unique characteristics, including photocatalytic behavior and bacteriostatic effects [23].

As illustrated in Table 2, the bactericidal efficiency of all samples against *E. coli* was greater than that observed for *B. cereus*. This difference can be explained by the variation in cell wall robustness and thickness between the two bacteria. Specifically, the cell wall thickness of *E. coli* is approximately 10–20 nm, whereas *B. cereus* exhibits a thickness of about 20–40 nm.

The antimicrobial activity of strontium titanate and zinc titanate nanopowders is closely related to their distinctive structural and compositional features. These nanopowders, with particle sizes generally below 50 nm, provide a large surface area for interaction with bacterial cells. Upon contact, their structure disrupts bacterial cell walls, thereby inhibiting growth and proliferation. The high surface-area-to-volume ratio of these particles further enhances their bactericidal efficiency by maximizing opportunities for interaction with microorganisms. Additionally, due to their nanoscale dimensions, the particles can penetrate bacterial cells more effectively, contributing to superior antimicrobial performance.

While their bactericidal potential is noteworthy, the durability of strontium titanate and zinc titanate nanoparticles is equally crucial for long-term application. In practical use, where repeated washing cycles are unavoidable, maintaining consistent antimicrobial activity is vital. Durability in antimicrobial materials refers to their resistance to wear, washing, and chemical exposure without losing their effectiveness. Both strontium and zinc titanate nanopowders demonstrate excellent durability, retaining more than 93% of their bactericidal activity against both Gram-positive and Gram-negative bacteria even after 15 washing cycles. This resilience is attributed to their high chemical stability and robust structural properties, which protect them from degradation under harsh conditions.

When comparing the bactericidal activity of the treated fabrics, woven (warp/weft) samples exhibited slightly higher antibacterial properties compared to nonwoven samples, though the difference was minimal and statistically insignificant. Additionally, samples treated with strontium titanate displayed superior antibacterial effects relative to those containing zinc titanate. Although both nanopowders share similar features and show strong antimicrobial performance, strontium titanate demonstrates enhanced photocatalytic activity, generating reactive oxygen species (ROS) under light exposure, which further intensifies bacterial cell destruction. This makes strontium titanate particularly effective in light-rich environments, such as hospital settings or outdoor applications.

Table 2. Bactericidal properties of specimens and their washing durability

Washing Cycle	**0**						**5**					
Bacillus cereus	97.4	95.2	96.8	95.2	97.2	95.6	97.3	95.2	96.6	95.1	97.5	95.3
Escherichia coli	100	98.6	100	98.5	100	98.9	100	98.6	100	98.4	100	98.4
Washing Cycle	**10**						**15**					
Bacillus cereus	97.3	95	95.3	94.6	97.1	94.9	97.2	94.9	94.7	93.1	97.4	94.8
Escherichia coli	100	98.5	99.1	97.7	100	99.1	100	98.3	97.3	95.1	100	98.5

3.2. Anti-inflammatory Analysis

The incorporation of anti-inflammatory properties into fabrics plays a significant role in alleviating discomfort for individuals with sensitive skin or dermatological conditions. Common symptoms such as redness, irritation, and itching are often aggravated by certain textiles; however, fabrics treated with nano-strontium titanate and zinc titanate integrate nanoparticles with anti-inflammatory activity. These nanoparticles contribute to reducing skin inflammation and providing relief for those with sensitivity issues.

According to the Winter method [24], paw diameter measurements were recorded before and after carrageenan injection using a caliper, with assessments repeated at one-hour intervals. The results, displayed in Figure 1 as an edema curve, showed that the control sample rapidly reduced swelling. In contrast, treated fabrics (samples A–D) demonstrated anti-inflammatory activity beginning at the 2-hour mark. After 5–6 hours, samples A and C exhibited similar effects, while samples B and D showed activity as well, though less pronounced than samples A and C (Figure 1.).

Nano-strontium titanate, composed of strontium, titanium, and oxygen, possesses distinctive characteristics that make it especially valuable for textile applications. When applied to fabrics, it enhances anti-inflammatory performance by reducing the release of inflammatory cytokines key mediators responsible for triggering inflammation. Upon contact with skin, these nanoparticles release ions that regulate inflammatory pathways, thereby decreasing redness, irritation, and itching. This is particularly advantageous for individuals with conditions such as eczema or dermatitis.

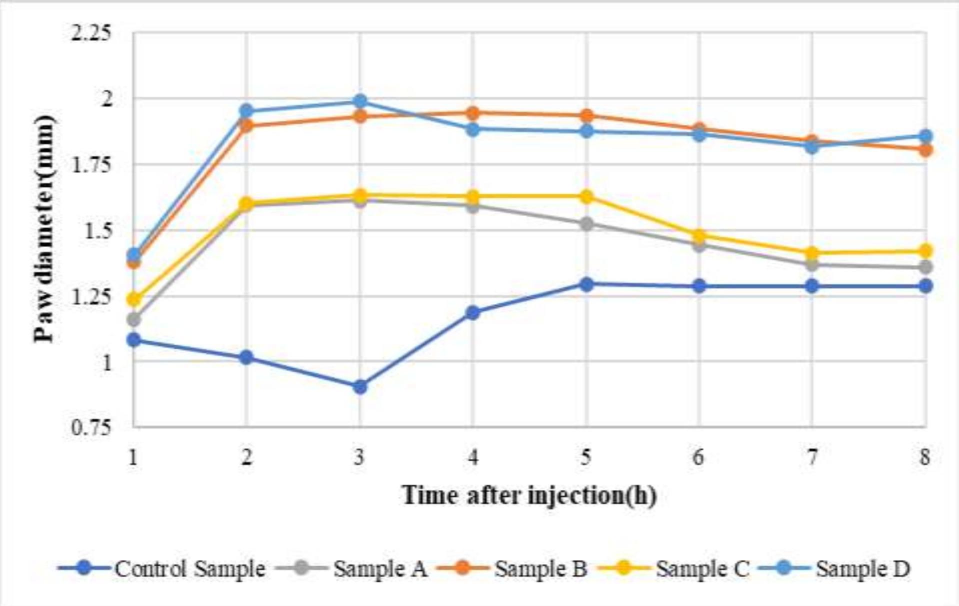

Figure 1. Inflammatory diagram of specimens

Additionally, nano-strontium titanate exhibits antioxidant activity, which further supports its anti-inflammatory role. Oxidative stress is a contributing factor in numerous inflammatory skin disorders, and antioxidants help neutralize free radicals, limiting tissue damage and promoting skin health. Integrating nano-strontium titanate into textile finishing leverages these combined properties, offering fabrics that provide comfort, therapeutic benefits, and suitability for individuals seeking skin-friendly clothing options

4. Conclusion

The findings of this research clearly demonstrate that the incorporation of nano strontium titanate ($SrTiO_3$) and nano zinc titanate ($ZnTiO_3$) into textile substrates imparts multifunctional characteristics, making fabrics more suitable for advanced applications in healthcare, protective clothing, and outdoor environments. Both woven and electrospun nonwoven fabrics benefited from the finishing process, exhibiting significant improvements in antibacterial, anti-inflammatory, and UV-shielding properties.

From the antibacterial perspective, treated samples showed stronger bactericidal activity against Escherichia coli compared to Bacillus cereus, which can be attributed to the structural differences in bacterial cell walls. This confirms the hypothesis that nanoparticle interaction with thinner Gram-negative bacterial walls leads to enhanced bactericidal efficiency. Furthermore, the excellent durability of these properties, with activity maintained above 93% even after 15 washing cycles, underscores the stability and practical applicability of both $SrTiO_3$ and $ZnTiO_3$ as antimicrobial agents. This long-term performance is a critical factor for real-world textile use, where repeated washing and exposure to external stressors are inevitable.

The study also highlights the unique advantage of strontium titanate over zinc titanate. While both nanomaterials enhanced antibacterial activity, strontium titanate-treated fabrics demonstrated superior performance, particularly due to their photocatalytic activity. The ability of strontium titanate to generate reactive oxygen species (ROS) under light exposure provides an additional mechanism for bacterial eradication, making it especially valuable in environments with high light intensity such as hospitals or outdoor applications. In contrast, zinc titanate's strong UV absorption and photocatalytic behavior make it more suitable for enhancing fabric resistance against UV degradation, thereby extending fabric lifespan.

In terms of anti-inflammatory properties, the incorporation of these nanoparticles into textiles offered significant benefits for individuals with sensitive skin or inflammatory skin conditions. The results based on the Winter method confirmed that nanoparticle-treated fabrics were capable of reducing edema and inflammation over time, with strontium titanate once again showing stronger effectiveness compared to zinc titanate. This suggests that beyond conventional antimicrobial functions, such nanomaterials can play an active role in therapeutic and comfort-oriented textile development.

When comparing fabric structures, woven samples exhibited slightly higher antibacterial performance than electro spun nonwoven fabrics; however, the difference was minimal and statistically insignificant. This finding indicates that both textile architectures are viable options, allowing flexibility in material design depending on the intended application.

Overall, the integration of nano strontium titanate and zinc titanate into textiles represents a promising strategy for producing multifunctional fabrics with enhanced durability, antimicrobial resistance, UV-blocking, and anti-inflammatory properties. These advancements not only open new avenues in smart and medical textiles but also highlight the potential of nanotechnology to address long-standing challenges in fabric performance and user comfort. Future studies should focus on optimizing nanoparticle concentration, evaluating long-term biocompatibility, and scaling up production methods to ensure industrial feasibility and consumer safety.

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