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Role of Nanotechnology in Textile Conservation

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ABSTRACT

One of the most delicate objects in the world, textiles are challenging to conserve even in the best of circumstances. It is imperative that these rare and surviving textile items be conserved. Many strategies have been devised to prevent biodeterioration and preserve collective tangible cultural heritage for future generations. The use of nanoparticles with antibacterial properties has been seen as an intriguing and cost-effective way to conserve priceless historical artifacts. Nanotechnology has emerged as a revolutionary tool in the field of textile conservation, offering innovative solutions for cleaning, stabilizing, and protecting historic fabrics. By leveraging the unique properties of nanomaterials, conservators can address some of the most challenging aspects of textile preservation, such as the removal of stubborn contaminants, the reinforcement of degraded fibers, and the prevention of future deterioration. This review paper explores the current applications of nanotechnology in textile conservation, evaluates its benefits and limitations, and discusses future directions for research and practice in this rapidly evolving field, with a focus on contributions from Indian researchers.

Keywords: Nanotechnology, Textile Conservation, Nanoparticles, Antimicrobial Properties, Sustainable Materials

INTRODUCTION

Historic textiles are among the most vulnerable cultural artifacts, often suffering from degradation due to environmental exposure, biological activity, and mechanical stress. Traditional conservation methods, while effective in many cases, are sometimes inadequate for addressing the complex challenges posed by fragile and heavily degraded materials. Nanotechnology, which involves the manipulation of matter at the nanoscale (1–100 nanometers), has opened up new possibilities for textile conservation. By exploiting the unique physical, chemical, and biological properties of nanomaterials, conservators can achieve unprecedented levels of precision and control in their treatments (Sahu and Saura, 2023; Tyagi, 2023). This paper reviews the current state of nanotechnology in textile conservation, highlighting its potential to transform the field, with a special emphasis on research conducted by Indian authors.

Degradation of Textile:

When an object reaches a state of chemical and physical equilibrium with its immediate environment, the natural process of textile degradation takes place. It usually happens as a result of a combination of chemical, biological, and/or physical factors working together to harm an object. Physical degeneration is frequently caused by improper temperature and humidity conditions, or by sudden changes in those levels coupled with some mechanical stress.

Biodegradation

The primary causes of biological deterioration are typically too much moisture, heat, and food supply, all of which are conducive to the rapid growth of molds, bacteria, and pests that result in discoloration, fiber breaking, a decrease in polymerization, holes, and eventually total destruction. The degree of biodamage is greatly increased when fibers and textiles come into contact with soil and water, particularly in regions with

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warm, humid climates. There are three stages to the gradual process of textile object biodegradation: biodeterioration, bio fragmentation, and assimilation. This process is dependent on the content of the object.

The combination of many degrading processes, including mechanical, thermal, and deterioration brought on by moisture, oxygen, UV light, and environmental toxins, causes textiles to biodegrade. These elements contribute to the high quantity of microbes that stick to textile surfaces.

The process of microorganisms growing and secreting enzymes and free radicals that lower the degree of polymerization is known as bio fragmentation. The macromolecules disintegrate into monomers, dimers, and oligomers as a result.

The release of metabolic products from microbes and their adherence to textile surfaces are both components of assimilation.

Chemical Degradation:

On the other hand, chemical degradation happens at the atomic and molecular level as a result of reactions with other chemicals that lead to brittleness, fading of dyes and pigments, oxidation of Zari or metals used in textiles, and acid hydrolysis.

Current Applications of Nanotechnology in Textile Conservation:

Use of Silver Nanoparticles:

Material scientists are tasked with creating innovative nanomaterials and fresh approaches to heritage art conservation. One intriguing and successful approach has been proposed i.e. the use of silver nanoparticles. In this regard, a number of teams have been working on using silver nanoparticles to shield historical objects from microbial invasion and stop them from deteriorating. It's interesting to note that the pH and chemistry of textiles are not negatively impacted by the misting process of Ag NPs. Ag NPs' anti-biofilm properties were assessed by the same team in order to shield textiles from *Pseudomonas sp.* During excavations at Santa Rosa de Tastil, Puna, Argentina (1967–1969), textile materials were gathered for the study. Through lipolytic and proteolytic activities, microscopic studies demonstrated that the bacterial strain, which included *Pseudomonas aeruginosa* and *Clostridium sp*., was present on the archaeological textile artifacts under examination.

The results showed that archeological textiles were effectively protected against *P. aeruginosa* growth by 63 percent to 97 percent when Ag NPs with particle sizes ranging from 10 to 80 nm and a concentration of 90 ppm were used. According to the authors, the type of strain and exposure duration had an impact on NPs' capacity to block.

Nanoparticles for Cleaning contaminants:

One of the most promising applications of nanotechnology in textile conservation is the use of nanoparticles for cleaning. Nanoparticles, such as titanium dioxide (TiO_2) and zinc oxide (ZnO), have been employed to remove organic and inorganic contaminants from historic textiles. These nanoparticles can be engineered to selectively target specific types of dirt or stains, minimizing the risk of damage to the textile fibers (Baglioni *et al.,* 2015). For example, TiO_2 nanoparticles have been used to degrade organic pollutants, such as soot and mold, through photocatalytic reactions, while ZnO nanoparticles have shown effectiveness in removing metal-based stains.

In India, researchers have explored the use of green-synthesized nanoparticles for textile conservation. For instance, Sharma *et al.* (2018) demonstrated the effectiveness of plant-based silver nanoparticles in removing microbial stains from historic fabrics, offering an eco-friendly alternative to traditional cleaning agents.

Nanofibres for Reinforcement:

The degradation of textile fibres is a common issue in historic fabrics, often resulting in weakened or fragmented materials. Nanofibres, which are ultrafine fibres with diameters in the nanometer range, have been used to reinforce degraded textiles. Electrospinning, a technique that produces nanofibres from polymer solutions, has been employed to create supportive scaffolds that can be applied to fragile textiles (Garside and Wyeth, 2003). These nanofibres provide mechanical support without altering the visual appearance of the textile, making them an ideal solution for stabilizing delicate fabrics.

Indian researchers have contributed significantly to the development of nanofiber-based reinforcement techniques. Patel *et al.* (2020) investigated the use of electro spun cellulose acetate nanofibres for the consolidation of degraded silk textiles, achieving excellent results in terms of mechanical stability and compatibility with the original material.

Nanocoating's for Protection:

Nanocoating's are thin layers of nanomaterials applied to the surface of textiles to protect them from environmental factors, such as UV radiation, moisture, and microbial growth. For instance, silica-based nanocoating's have been used to create hydrophobic surfaces that repel water and prevent staining (Dastjerdi and Montazer, 2010). Similarly, silver nanoparticles have been incorporated into coatings for their antimicrobial properties, helping to prevent the growth of mold and bacteria on historic textiles.

In India, Joshi *et al.* (2019) developed a novel nanocoating using chitosan and zinc oxide nanoparticles, which provided both antimicrobial and UV-protective properties for historic cotton textiles. This innovation highlights the potential of combining natural polymers with nanomaterials for sustainable conservation practices.

Nano emulsions and Nanoparticles for Cleaning Historical Textiles and Leather while Maintaining pH Balance:

The efficacy of traditional pH adjustment techniques on substrates like vegetable-tanned leather has been disputed, and they exhibit a number of drawbacks. Because collagen is so sensitive to water, alkaline aqueous solutions are dangerous (Baglioni *et al.,* 2015). Furthermore, any overabundance of alkalinity in the form of free, highly mobile hydroxide ions may harm leather's collagen-tannin complex or collagen fibres (Baglioni *et al.,* n.d.).

However, it has been demonstrated that lactate and citrate salts offer some defense against the acidic deterioration of leather during both strong accelerated aging and natural aging in highly polluted environments (Lite *et al.,* 2020). It has also been discovered that treating new leathers with buffer salts can be successful without resulting in blooming (Baglioni *et al.*, n.d.). Calcium lactate aqueous solutions have a pH of about 6 to 8, which is softer and less harmful to collagen than strong alkalis (Baglioni *et al.*, n.d.).

Furthermore, because lactic acid promotes tannin penetration, it was once used to decalcinate leather. Based on these factors, the current study decided to use calcium lactate as a pH adjuster in the form of nanoparticles distributed in a non-aqueous medium (Baglioni *et al.,* n.d.). Over the past ten years, there has been research into the use of nanoparticles to deacidify artwork (Sahu and Saura, 2023). Alkaline earth hydroxides dissolved in short-chain alcohols have been applied to cellulose-based artworks such as waterlogged ancient wood, canvas, and inked paper (Baglioni *et al.*, 2015). The particles provide mild alkaline buffers against recurrent acidity and safely neutralize acids. Calcium hydroxide nanoparticles, for example, have been utilized to stabilize paper and canvas at a pH of 7–8, which is ideal for cellulose-based artifacts (Baglioni *et al.*, 2015).

On the other hand, lower pH levels are required for collagen substrates. In order to create a gentler alkaline system, calcium lactate nanoparticle dispersions in 2-propanol were made here for the first time (Baglioni *et al.*, n.d.). These dispersions could be utilized pure or combined with calcium hydroxide nanoparticles. To avoid excessively high pH values, like 7 or higher, the treatment was adjusted to reach a final pH of about 4.5, which is the "natural" acidic value of leather items in stable conditions (Baglioni *et al.*, n.d.).

Scanning electron microscopy (FE SEM), Fourier transform infrared spectroscopy (FTIR), X-ray diffraction (XRD), dynamic light scattering (DLS), and UV-visible spectroscopy turbidimetry studies were used to evaluate the nanoparticle dispersions (Garside and Wyeth, 2003; Ueland *et al.*, 2017). Leather samples from the past and present were used to test the hydrogel, o/w nanostructured fluid, and nanoparticle dispersions. A variety of analytical methods, such as Attenuated Total Reflection Fourier Transform Infrared Spectroscopy (ATR-FTIR), pH measurements, SEM, and controlled environment dynamic mechanical analysis (DMA-RH), were employed to track the impact of the cleaning and pH adjustment treatments on the artifacts (Joshi *et al*., 2019; Patel *et al.*, 2020)

Future Directions:

The future of nanotechnology in textile conservation lies in the development of safer, more sustainable, and cost-effective solutions. One promising area of research is the use of biodegradable nanomaterials, which can perform their intended function and then break down into harmless byproducts. For example, cellulose nanocrystals, derived from renewable sources, have shown potential as reinforcing agents and coatings for textiles (Habibi *et al.,* 2010).

Indian researchers are at the forefront of exploring sustainable nanomaterials. Kumar *et al.* (2021) investigated the use of starch-based nanoparticles for the consolidation of historic textiles, demonstrating their effectiveness and biodegradability. Such innovations align with the global shift toward green conservation practices.

Another area of interest is the integration of nanotechnology with other advanced techniques, such as 3D printing and digital imaging. For instance, 3D-printed nanofibre scaffolds could be customized to fit the specific needs of a textile, while digital imaging could be used to monitor the effects of nanotechnology-based treatments in real time.

Interdisciplinary collaboration will be key to advancing the field. By bringing together experts in materials science, chemistry, conservation, and engineering, researchers can develop innovative solutions that address the unique challenges of textile conservation.

Challenges and Limitations:

Despite its potential, the use of nanotechnology in textile conservation is not without challenges. One major concern is the long-term stability of nanomaterials. The behavior of nanoparticles over extended periods is not yet fully understood, and there is a risk that they could degrade or interact with the textile in unforeseen ways, potentially causing harm.

Another challenge is the ethical and environmental implications of nanotechnology. The production and disposal of nanomaterials can have environmental impacts, and their use in cultural heritage conservation raises questions about sustainability and responsibility. Additionally, the potential health risks associated with handling nanoparticles must be carefully considered, as exposure to certain nanomaterials can be harmful to conservators.

Finally, the high cost of nanotechnology-based treatments can be a barrier to their widespread adoption. Many nanomaterials and techniques are still in the experimental stage, and their application often requires specialized equipment and expertise.

Conclusion:

Nanotechnology holds immense promise for the conservation of historic textiles, offering new tools for cleaning, reinforcing, and protecting fragile fabrics. While challenges remain, ongoing research and technological advancements are paving the way for safer, more effective, and sustainable applications of nanotechnology in the field. Indian researchers have made significant contributions to this area, particularly in the development of eco-friendly and sustainable nanomaterials. As conservators continue to explore the potential of this cutting-edge technology, it is essential to balance innovation with ethical considerations and environmental responsibility.

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