

SUSTAINABLE TEXTILE FINISH EMPOWERED BY NANOTECHNOLOGY

Ankita Mishra^a, Sumit Kumar^a, Kamaljeet Singh^b, Deepak Mehra^a,

^aNATIONAL INSTITUTE OF FASHION TECHNOLOGY Fashion Technology Department Bhubaneswar,

^bNATIONAL INSTITUTE OF FASHION TECHNOLOGY Fashion Technology Department, Kangra

Corresponding author: Dr. Deepak Mehra, deepak.mehra@nift.ac.in

ABSTRACT:

The textile industry, renowned for its environmental impact, has initiated a transformative shift towards eco-friendly practices, particularly in finishing methods. This paper thoroughly examines innovative approaches and sustainable practices adopted by manufacturers to mitigate environmental harm while also exploring the integration of nanotechnology and nano-coating in textile finishing, aiming to boost the effectiveness and utility of textile materials. It also covers eco-friendly textile finishing, emphasizing natural dyes, waterless dyeing techniques, and sustainable chemical alternatives. Waterless dyeing methods, including air dyeing and digital printing, significantly diminish water consumption and chemical usage, preserving colour vibrancy and fabric quality. Manufacturers embrace organic and recycled materials, implementing energy-efficient production processes and prioritizing supply chain transparency and certifications. This paper explores the fundamental principles of nanotechnology, highlights the challenges in traditional textile finishing methods, and discusses the innovative applications and benefits of nano coatings in textile engineering, laying the groundwork for a more environmentally conscious and responsible industry.

1.INTRODUCTION:

The textile industry stands as a colossal contributor to global pollution, primarily through its extensive use of chemicals, substantial water consumption, and vast carbon footprint. Within this industry, finishing processes wield a particularly significant impact on the environment. Recognizing this, a pressing need for transformative change has emerged, urging a reevaluation of conventional practices towards eco-friendly alternatives [1]. This

research endeavours to explore the dynamic landscape of eco-friendly approaches in textile finishing and the sustainable practices adopted by manufacturers, reflecting an urgent global necessity for environmental responsibility. The innovative drive towards eco-friendly textile finishing methods marks a pivotal turning point in the industry's trajectory. Textiles are dyed and finished with a multitude of chemicals, using lots of water. Every year, over 700,000 tonnes of dyes and pigments are made, offering more than 100,000 types [2]. But, when colored fabrics are washed, they release harmful liquid waste containing dyes, pigments, and leftover chemicals—wasting around 280,000 tons of dyes yearly [2]. This movement not only ensures a reduction in hazardous chemical use but also presents a spectrum of unique colors and textures, fostering an aesthetic edge to sustainable practices.

Simultaneously, nanotechnology is revolutionizing the textile industry, from advanced applications like nanocomposite fibres and intelligent polymeric nano coatings to conventional textiles. These innovations are not only enhancing performance but also introducing new functionalities. The benefits include improved repeatability, reliability, and robustness [3]. Integrating nanoparticles into traditional textile processes like finishing, coating, and dyeing significantly boosts product performance and adds functionalities previously unattainable.

The exploration of these eco-friendly textile finishing methods and the burgeoning sustainable practices among manufacturers represents a significant paradigm shift in an industry often criticized for its environmental toll. This research endeavours to delve deeper into these innovative approaches and practices, underscoring the potential for a more environmentally conscious and responsible textile industry.

2.ECO-FRIENDLY APPROACHES IN TEXTILE FINISHING:

2.1. Natural Dyes and Pigments:

The resurgence of natural dyes and pigments in textile finishing epitomizes a critical departure from the environmentally detrimental synthetic dyes commonly employed.

Natural dyes, derived from sources such as plants, minerals, and organic matter, represent a sustainable alternative, embodying biodegradability and reduced ecological impact [3]. Manufacturers are increasingly exploring innovative extraction methods and optimizing colourfastness to enhance the viability and scalability of natural dyes in industrial settings. Beyond their environmental benefits, these natural pigments offer a diverse palette of rich, nuanced colours, presenting an exciting opportunity for textile designers and manufacturers to embrace both sustainability and artistic expression.

2.2. Waterless Dyeing Techniques:

Water scarcity has emerged as a pressing global concern, prompting the evolution of waterless dyeing techniques as a compelling solution in textile finishing. Techniques such as air dyeing, foam dyeing, and digital printing have gained prominence for their ability to drastically curtail water consumption and chemical utilization [4]. Their implementation maintains the vibrancy and quality of textile products while significantly reducing the environmental footprint of the manufacturing process. Understanding the technological advancements, scalability, and compatibility of these techniques with different textile materials and manufacturing scales are critical areas of exploration to foster widespread adoption and further innovation in this realm.

2.3. Nanotechnology:

Following are four main parts of textile finishing department in nanotechnology which are:

2.3.a. Nano finishing

Nanomaterials have revolutionized textile finishing by enhancing fabric properties. They enable improved stain resistance, UV protection, and antibacterial qualities [5]. Nanoparticles have the potential to be utilized in the creation of self-cleaning fabrics, reduce water and energy consumption during dyeing processes [5], and enhance wear resistance. Overall, nanomaterials have significantly boosted up the performance and sustainability of textiles in the garment industry.

2.3.b. Nanocoating

Nanocoating in textile finishing involves applying nanoscale materials to enhance fabric properties. It offers improved water repellence, stain resistance, and UV protection, while maintaining breathability [5]. Nanocoating can also make textiles self-cleaning and antimicrobial, extending the life and functionality of garments. This innovation has a considerable impact on creating high-performance and sustainable textiles for various applications in the fashion and technical textile industries.

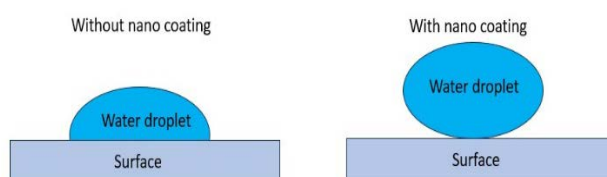


Fig. 1.1 Shows the impact of nano coating

2.3.c. Polymeric Nanocomposite Coating

Polymeric nanocomposite coatings in textile finishing enhance fabric properties like durability, water resistance, and UV protection [5]. By incorporating nanoscale materials into coatings, textiles can achieve maximum performance with minimal weight and thickness, rendering them ideal for various applications, from sportswear to outdoor gear. Nanocomposite coatings contribute to innovative and high-performance textile products. Fig.1.2. shows how nanocomposite is being formed.

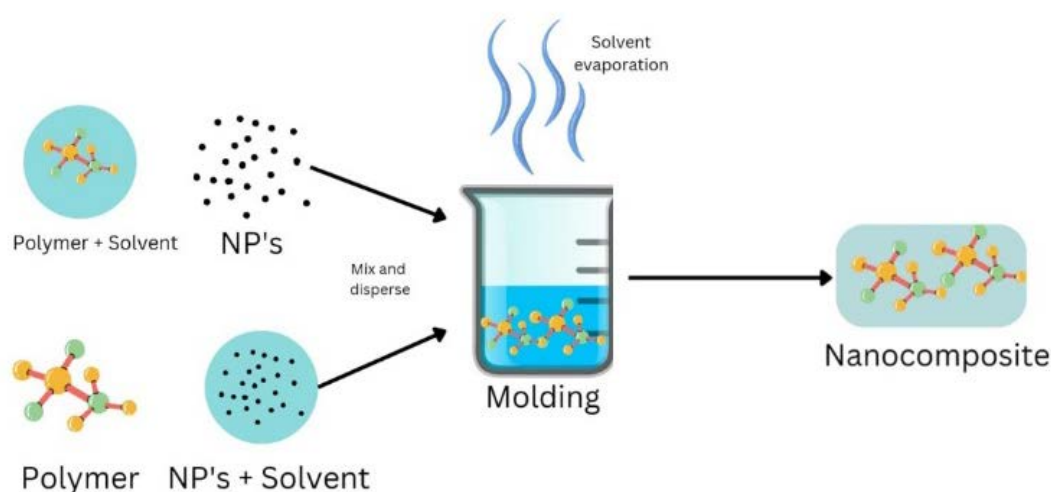


Fig. 1.2. Shows the formation of nanocomposite

2.3.d. Nano dyeing

Nano dyeing, the utilization of nanotechnology in textile finishing presents numerous benefits including reduced water and energy consumption, improved color fastness, and enhanced fabric properties. It allows for precise and efficient dye penetration, resulting in vibrant and long-lasting colors. Additionally, nano dyeing can minimize the ecological footprint caused by traditional dyeing processes, making it a promising innovation in the textile industry. Fig.1.3. shows how a fabric is being dyed using nano emulsion

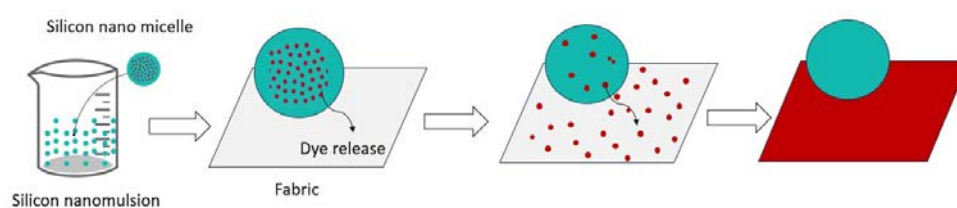


Fig. 1.3. Shows the nano dyeing process

Following are the textile properties enhanced by Nanotechnology: Water Repellence, Soil Resistance, Wrinkle Resistance, Anti-bacterial, Anti-static, UV Protection, Flame Retardation, Enhanced Dye Ability, Self-cleaning Fabrics, etc.

2.3.e. Water Repellence:

Nano-Tex enhances the water-repellent quality of fabric by introducing tiny hydrocarbon structures called nano-whiskers, that are 1/1000th the average dimensions of a standard cotton fiber [7]. These whiskers are integrated within the fabric to create a soft, fuzzy texture without compromising the fabric's strength. The gaps among these whiskers are diminutive compared to a typical water droplet but still surpassing in size compared to water molecules, allowing water to stay on the uppermost part of the whiskers and not penetrate the fabric's surface. However, if pressure is applied, fluid can still permeate the fabric. Importantly, this performance is long-lasting, and the fabric remains breathable.

2.3.f. UV Protective Finish:

Garments serve two crucial functions: protecting wearers from adverse weather conditions and shielding them from the sun's harmful rays. Ultraviolet radiations, falling within the wavelength range of 150 to 400 nm [7], are known as UV rays. A fabric's ability to inhibit UV radiation is improved when it contains dyes, pigments, delustrants, or UV absorbers that absorb UV rays and obstruct their penetration to the skin [6]. Metal oxides such as zinc oxide are more reliable UV blockers in contrast to organic UV-blocking agents [7]. Utilizing nano-sized ZnO particles significantly enhances a fabric's UV-blocking capability due to their expanded surface area and strong UV absorption.

In the context of antibacterial treatments, ZnO nanoparticles outperform nano-silver with regards of cost-effectiveness, maintaining the fabric's whiteness, and providing UV protection. Fabrics processed with UV absorbers guarantee that they deflect harmful UV rays from the sunlight [7], diminishing a person's exposure to UV radiation and safeguarding their skin from potential damage. The required level of skin protection varies depending on factors such as UV radiation intensity, geographical location, time of day, and season. This protection level is measured as SPF (Sun Protection Factor), with higher SPF values indicating increased defence against UV radiation.

2.3.g. Self-Cleaning Fabrics:

Nanotex, an American company has developed and marketed a Cotton fabric renowned for its self-cleaning properties as Nano-Care [7]. Since 1990, this technology has been applied to jeans and khakis, creating Nano-Care fabrics engineered to resist stains [7]. These fabrics are crafted by modifying the cylindrical structure of cotton fibers, the fundamental building blocks of the fabric. This alteration reframes the fibers at the nano-level, imparting them with enhanced stain-resistant properties. At the nanoscale, these cotton fibers resemble tree trunks. Through nanotechnology, these "tree trunks" are laminated with tiny whiskers, creating a cushion of air around each fiber. When water touches the fabric,

it forms beads on the tips of these tiny structures, akin to whiskers. These beads then compress the air trapped within the gaps between the whiskers, resulting in additional buoyancy. This intricate mechanism renders the fabric highly resistant to wetting, achieving a state of super-hydrophobicity [7].

Additionally, these whiskers reduce the contact points for dirt on the fabric's surface. When water is applied to a dirty fabric, the dirt tends to stick more readily to the water than to the fabric surface as shown in Fig.1.4. As the water beads and easily slides off the fabric's surface, it carries away the dirt. This concept of "soil-cleaning" takes inspiration from the lotus plant's leaves [7].

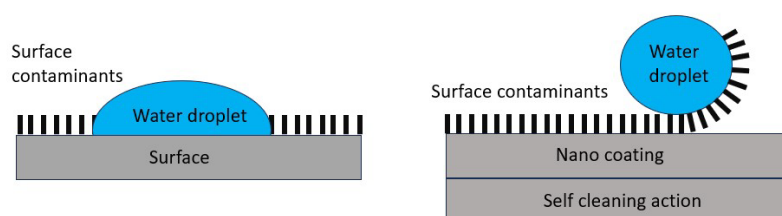


Fig. 1.4. Shows the self cleaning property enhanced by nano technology

2.3.h. Anti-Static Finishes:

Synthetic fibres such as nylon and polyester have a tendency to accumulate static charge due to their low water absorption capabilities. In contrast, cellulosic fibres contain more moisture, which helps dissipate static charges and prevent their buildup. Since synthetic fibres have poor natural anti-static properties, researchers have explored ways to enhance their anti-static characteristics using nanotechnology.

The study revealed that nanoscale materials like titanium dioxide (TiO_2), zinc oxide (ZnO) whiskers, antimony-doped tin oxide (ATO) [7], and silane nanosol can confer anti-static characteristics to synthetic fibers. TiO_2 , ZnO , and ATO exhibit electrical conductivity, enabling effective dissipation of static charges accumulated on the fabric [7]. Conversely, silane nanosol improves anti-static properties by employing

silane gel particles on the fiber's surface. These particles absorb moisture from the surrounding air via amino and hydroxyl groups, as well as bound water.

2.3.i. Nano Technology for Wrinkle Free Treatment:

Nano-Text has introduced an innovative wrinkle-free treatment based on nanotechnology, aiming to provide enhanced optimized performance while maintaining the durability and resilience of fabrics. This presents an alternative to conventional wrinkle-free treatments, which frequently rely on harsh chemicals and processes that can compromise a fabric's tear resistance and tensile strength [7]. While traditional wrinkle-free textiles are favoured for their ease of care, they may not be compatible with certain fabrics and garment styles, such as lightweight materials or form-fitting clothing.

In some cases, fabrics must be reinforced or made more robust to endure the fibre degradation induced by conventional wrinkle-free solutions. Existing technologies either come with restrictions in their applicability across all fabric types, or brands and retailers must bear extra costs to mitigate the detrimental impacts of wrinkle-free treatments. Nano-Text's innovative Fortify DP technology harnesses a nano-scale molecular structure that penetrates deep into fibres, enhancing wrinkle resistance [7]. Additionally, it incorporates a longer and more flexible cross-linking chain, which reduces the stress on fibres when under tension, consequently mitigating the substantial loss of strength linked with conventional wrinkle-free chemistry.

2.3.j. Bacteria-Resistant Treatments:

To provide antibacterial qualities, zinc oxide, nano-sized silver and titanium dioxide are employed [8]. Compounds and metal ions exhibit a level of sterilizing effectiveness. It is believed that some oxygen present in the air or water undergoes a transformation into active oxygen through catalysis with metallic ions, leading to the dissolution of organic substances and generating a germ-killing impact [8]. Utilizing nano-sized particles increases the particle concentration per surface area, maximizing the antibacterial effects.

Following are the application area of nano technology in textile finishing:

- I. High-performance sky wax, breathable waterproof sky jackets, wrinkle-resistant, and stain-repellent garments have recently been applied in textile finishing .
- II. The fabric becomes stained and water-resistant due to nano whiskers. Additionally, it also attains breathability, distinguishing it from resin finishes
- III. Furthermore, the whiskers provide water and oil repellency, exceptional durability, breathability, and innate wrinkle resistance.
- IV. The nano net fully envelops the core fibres, imbuing synthetic fibres with linen-like properties, including the absorbency characteristic of linen in polyester fibres. This transformation alters synthetic fibres to emulate the feel of cotton and linen, promoting moisture absorption from the body and delivering a cooling effect .
- V. The 'Wrap nano sheet' envelops fibres entirely, enhancing fabric strength and durability. It elevates color fastness, crease retention, and resistance to static electricity .

3.SUSTAINABLE PRACTICES ADOPTED BY MANUFACTURERS:

3.1. Adoption of Organic and Recycled Materials:

The adoption of organic and recycled materials marks a significant shift in the textile manufacturing landscape. Organic cotton, hemp, and recycled polyester are becoming increasingly prevalent choices for manufacturers aiming to reduce the environmental impact of their products [9]. These materials offer numerous benefits, from reduced pesticide use in organic cotton farming to lower carbon footprint in the production of recycled polyester. Furthermore, the growing consumer demand for sustainable and eco-friendly products propels the utilization of these materials in the textile industry. Exploring the scalability, challenges in sourcing, and enhancing the durability and versatility of these materials becomes crucial for widespread adoption and increased market penetration.

3.2. Energy-Efficient Production Processes:

Textile manufacturers are fervently embracing energy-efficient production processes to curtail their environmental footprint. Implementing technologies such as solar panels, LED lighting, and optimized machinery not only reduces energy consumption but also minimizes greenhouse gas emissions during production [9]. Evaluating the effectiveness of these technologies, their compatibility with different manufacturing scales, and the return on investment becomes pivotal in ensuring their widespread adoption. Additionally, a comprehensive understanding of the challenges, regulatory support, and the economic viability of these technologies is crucial for their integration into conventional manufacturing practices.

3.3. Supply Chain Transparency and Certification:

Promoting supply chain transparency and obtaining certifications such as the Global Organic Textile Standard (GOTS) [9] or Oeko-Tex Standard 100 demonstrates a commitment to sustainable and eco-friendly practices [9]. These certifications verify compliance with stringent environmental and social criteria throughout the production process. Assessing the challenges in obtaining and maintaining these certifications, their impact on consumer perception, and their role in ensuring a transparent and ethical supply chain becomes a critical focal point for manufacturers aiming to meet evolving consumer expectations and industry standards [9].

4.COMPARATIVE ANALYSIS OF TRADITIONAL VS ECO-FRIENDLY TEXTILE TECHNIQUES:

4.1. Traditional Textile Techniques

Traditional techniques encompass a wide array of practices deeply rooted in cultural heritage and historical significance [10]. These methods often involve processes like hand-weaving, natural dyeing, and artisanal craftsmanship. While they hold cultural value and

authenticity, traditional techniques generally utilize extensive amounts of water, chemical dyes, and energy, contributing to environmental pollution and resource depletion [10,11].

4.2. Eco-Friendly Textile Techniques

Eco-friendly techniques, in contrast, focus on minimizing environmental impact throughout the production cycle. These methods employ sustainable materials such as organic cotton, hemp, or bamboo, reducing reliance on synthetic fibres [10,11]. Additionally, they emphasize the use of natural dyes, innovative dyeing processes, and efficient water management systems, which significantly lower water consumption and pollution. Furthermore, these methods often incorporate energy-efficient production processes, including solar and wind energy, to reduce the carbon footprint. Integrating nanotechnology can further enhance sustainability by enabling the development of advanced materials and processes that optimize resource usage and minimize environmental impact.

5. COMPARATIVE ANALYSIS:

5.1. Environmental Impact

The environmental impact of traditional textile techniques is substantial, primarily due to the extensive use of chemical dyes, water, and energy. Chemical dyes, often synthetic, not only contribute to water pollution but also pose health risks to both workers and surrounding communities. Moreover, the significant water usage in these processes contributes to water scarcity, particularly in regions where textile production is concentrated. Energy consumption, primarily sourced from non-renewable fossil fuels, further amplifies the ecological footprint of traditional techniques.

In contrast, eco-friendly textile techniques significantly reduce the environmental burden. Natural dyes derived from plants, minerals, or other organic sources are biodegradable and non-toxic, significantly minimizing water pollution. Additionally, the implementation of closed-loop systems for water usage and the utilization of recycled water in eco-friendly processes substantially reduce water consumption, contributing to conservation efforts

[10]. Moreover, it was anticipated that after 10-15 years, meeting the global production annually demand of \$1 trillion would result in the development of approximately 2 million new job opportunities. Nanotechnology also presents opportunities for environmental advantages. By using lesser resources without sacrificing performance, nanotechnology has the ability to conserve raw materials and enhance overall quality of life [10].

5.2. Production Efficiency

Traditional textile techniques, often reliant on manual labour and time-intensive processes, might hinder large-scale manufacturing and production efficiency. Hand-weaving, for instance, while producing unique and high-quality fabrics, can be slow and labour-intensive [11]. Furthermore, the reliance on artisanal skills for intricate patterns and designs can limit the scalability of these techniques, affecting mass production.

Eco-friendly methods, however, have made significant strides in technology and innovation. Advanced machinery and technology in eco-friendly processes have augmented production efficiency while retaining product quality. For instance, developments in sustainable fabric manufacturing have enabled larger-scale production of organic textiles without compromising on quality. The integration of automation and technological advancements has reduced production time and increased output, allowing eco-friendly techniques to compete more effectively in the fast-paced textile market [11].

When it comes to manufacturing processes for nano textiles, a fundamental distinction is made between those involving the application of nanoparticles and those using nanostructures (such as nanometre-thin fibres and nano porous fibres) without synthetic nanoparticles. Nanoparticles can be integrated into a synthetic material (polymer), from which fibres with nanoscale or larger diameters are spun, creating nanocomposite materials. Alternatively, nanometre-thin fibres can be generated from synthetic materials or cellulose without synthetic nanoparticles. In this case, the term "nanofiber" is used to describe the fibres' extremely small diameter.

5.3. Economic Viability

The economic viability of traditional textile techniques versus eco-friendly methods is a multifaceted consideration. Traditional techniques, deeply rooted in cultural heritage and

craftsmanship, might face economic challenges due to the higher costs associated with skilled artisanal labour and the rising prices of raw materials [11]. Furthermore, potential legal and market constraints concerning chemical usage and waste disposal could lead to additional costs and decreased profitability.

While the initial investment for eco-friendly techniques could be higher due to technological upgrades, sustainable material costs, and infrastructure changes, the long-term benefits significantly outweigh these initial costs. Reduced operational costs stemming from lower resource consumption, compliance with environmental regulations, and the growing market demand for sustainable and ethical products contribute to the economic viability of eco-friendly techniques [12].

Simultaneously, the distinctive characteristics of nanomaterials have captured the attention of scientists, researchers, and businesses, owing to their substantial economic possibilities. According to the National Science Foundation, the market for nano-related products and services is projected to reach a value of \$1 trillion by 2015, exceeding the combined markets of the telecommunications and information technology industries. Nanotechnology is projected to generate several hundred billion Euros in the coming decade.

The textile industry has embarked on a transformative journey towards eco-friendly practices and sustainable approaches in textile finishing, marking a pivotal shift in an industry traditionally criticized for its significant environmental footprint. Throughout this research, we have delved into the innovative and novel methods embraced by manufacturers, as well as explored the burgeoning landscape of sustainable textile finishing, recognizing the paramount importance of environmental responsibility in the production of textiles.

6. CONCLUSION:

In conclusion, the journey towards sustainable textile finishing and eco-friendly practices embodies a collective commitment towards a healthier environment, ensuring a balance between manufacturing needs and environmental responsibility. The dynamism and

innovation in these practices hold the promise of a more sustainable and environmentally conscious future for the textile industry.

Additionally, the integration of nano coatings and nanotechnology into textile finishing processes represents a notable leap forward in enhancing the functionality and performance of textiles. This creative approach has unlocked a wide range of possibilities, from creating self-cleaning fabrics to improving UV protection, antibacterial properties, and wrinkle resistance. Nanotechnology has revolutionized the textile industry by allowing for precise control and manipulation of material properties at the molecular level.

Moreover, nanotechnology has not only elevated the quality and durability of textiles but also contributed to eco-friendly solutions, reducing resource consumption while maintaining or enhancing performance. As the demand for advanced textiles continues to grow, the implications of nanotechnology in textile finishing are poised to play a vital role in meeting consumer expectations and addressing industry challenges.

With the ever-evolving capabilities of nano coatings, we can expect even more remarkable progressions in textiles, further enhancing their functionality and overall utility in various applications. This dynamic synergy between nanotechnology and textiles holds tremendous potential for shaping the future of clothing and technical fabrics.

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