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The Applications of Microencapsulation in Different Textile Finishing

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Abstract

Science has created several technologies for eco-friendly textile manufacturing, such as microencapsulation. Microencapsulation is a cutting-edge technique that has been used to imbue fabrics with functional properties such as antibacterial activity, smell, mosquito repellency, UV protection, and thermoregulation. The volatile and non-volatile components can be microencapsulated inside a thin polymeric film, resulting in delayed chemical release and long-term functional impact. Microencapsulation is a good technique for protecting core chemicals against moisture, light, alkalinity, evaporation, and oxygen reactions. If functional agents were encapsulated, the fabric's functioning may be anticipated to last longer. Colorants, enzymes, PCM, softeners, perfumes, flame retardants, insect repellents, water repellents, antimicrobials, and deodorants are some of the substances that may be found in microcapsules. Crosslinking agents are used to create a lasting binding between capsule-based compounds and textile materials, which gives resistance to washing. Commercial capsules are applied to fabric using acrylics or polyurethanes as the cross-linker at a drying temperature of approximately 100 C and thermo-fixation conditions of 110 to 130 C. This study focuses on the primary reasons for microencapsulation, the characteristics of microcapsules, microencapsulation technologies, and the use of microcapsules for functional textiles.

Keywords: Microencapsulation, Functional textiles, Methods, Controlled release.

Introduction

"Small is better" would be an excellent tagline for microencapsulation, a technique that surrounds tiny particles or droplets with a coating to create miniature capsules with a variety of beneficial features. The substance within the microcapsule is known as the core, internal phase, or fill, whereas the wall is known as a shell, coating, or membrane. The majority of microcapsules have sizes of a few micrometres. [1]

The technique of encapsulating a material inside a small capsule is known as microencapsulation. Microcapsules and nanocapsules are the names given to these capsules. The material contained within the capsule might be a gas, liquid, or solid. The capsule wall can be made of a variety of materials, including wax, plastic, or biopolymers such as proteins or polysaccharides. [2, 3]

It refers to the process of encasing the core components (gases, solid particles, and liquid droplets) in the wall materials (polymers). The essential components are entirely covered by a thin layer of wall material or incorporated into a polymer matrix, resulting in a micro-size capsule with several functional properties. An internal phase is defined as a core, filler, or active microcapsules, whilst the encasing material is defined as a shell, coating, membrane, wall, or carrier. [3, 4]

There are several motivations for microencapsulation. In some circumstances, the core must be isolated from its surroundings, such as when protecting vitamins from the degrading effects of oxygen, slowing the evaporation of a volatile core, increasing the handling capabilities of a sticky substance, or protecting a reactive core from chemical assault. In other circumstances, the goal is not to totally separate the core but to regulate the pace at

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which it exits the microcapsules, like in the controlled release of medications or insecticides. [4, 5]

The expenses of manufacturing are determined by the coating material, solvent, equipment, and labor. Coating-material prices vary widely, and the least appropriate material is usually utilized. Coatings that can be applied without the need of a solvent or water are preferable. Environmental and safety standards raise the cost of processes that employ volatile organic solvents significantly. [3, 6]

Objectives of Encapsulation

Encapsulation of active substances is done for a variety of businesses for one or more of the following reasons: Protecting active components against oxidation, heat, acidity, alkalinity, moisture, or evaporation by converting liquids to powders. [7, 8] By preventing components from interacting with other chemicals in the system, degradation or polymerization may occur. masking the flavor or odor of unpleasant tastes or smells Improving an ingredient's handling before processing, Controlled or targeted release of active substances Keeping workers and end users safe from harmful chemicals. [3, 6, 7]

Characteristics

Size and size distribution: A small size boosts mechanical strength while also making application easier. [9]

- Loading fraction: This is the weight ratio of the microcapsule's core to its wall; the greater this ratio, the better the manufacturing efficiency, but the worse the stability. [3]
- Thermal stability: The microcapsule should be stable at higher temperatures during manufacture and application. [3, 7]
- Release properties: The rate of release from microcapsules is mostly determined by the structure of the polymer wall, which is regulated by the conditions used in preparation. [10] The release rate is heavily influenced by wall properties such as crystallinity, cross-link density, and porosity. The release rate decreases significantly as the crystallinity and cross-link density of the wall increase. [3, 6, 10]

Mechanisms of release Encapsulated materials have a variety of release methods that allow the core component to be released in a controlled, sustained, or targeted manner. Three mechanisms exist for core material to be released from capsules: mechanical rupture in the capsule wall, wall material getting dissolved in a changing environment, or wall melting due to temperature change. Less well-known processes include low wall erosion (ablation) and biodegradation. Some of the uses for these long-lasting textile materials include insect repellents, cosmetics, scents, deodorants, and medical textiles. The migratory molecular weight (low or high) can also be utilized to categorize the releasing mechanism. [6, 7, 11, 12]

To produce such effects in permeability and non-permeable microcapsules, eight unique release mechanisms have been documented.

a) External pressure: The microcapsules are mechanically broken as a result of this process.[13]
b) Internal pressure: might potentially cause the microcapsule wall to shatter, for example, if the core shell includes compounds that, under certain conditions (e.g., radiation activation), are transformed into gaseous products, as in the case of the manufacturing of light synthetic leather.[14]
c) Microcapsule walls abrasion: In the case of scent release, this method is commonly utilized.
d) Burning: When the temperature rises to a certain level, fire retardants are released.
e) Radiation: This method can trigger photographic and light-sensitive processes, resulting in changes in the color of these fabrics due to the release of microencapsulated dyes.[7, 15]
f) Temperature Changes: Temperature variations can aid core material release. There are two separate processes for release:
    - Temperature-sensitive: When the crucial temperature is reached, the wall expands and falls.
    - Fusion-activated: The wall dissolves as the temperature rises.
g) Chemical reactions: This is the situation with microcapsules containing chemicals added to textile washing or cleaning formulations that are released throughout the wash cycle due to chemical composition or pH changes.
h) Enzymatic degradation: This is the case with microcapsules, which are destroyed by enzymes under strict circumstances.[6, 7, 16]

Morphology of microcapsules

Microcapsules are composed of two parts: the core and the shell. The core (intrinsic component) includes an active ingredient (for example, a hardener), whereas the shell (extrinsic component) permanently or temporarily shields the core from the external environment. [17]

The core material, which is described as the precise substance to be coated, might be solid, liquid, or gaseous. The three main types of core materials are solution, dispersion, and emulsion. The core material composition can vary because the liquid core may comprise distributed and/or dissolved

material. The solid core contains active chemicals, stabilizers, diluents, excipients, and release-rate retardants or accelerators. The ability to vary the composition of the core materials provides great flexibility, and taking use of this characteristic typically allows for successful design and development of desired microcapsule properties. [18]

Shell material: Shell type and form are important in diffusion, permeability, and controlled release applications. The shell material used determines the physical and chemical properties of the produced microcapsules/microspheres. [7, 18]

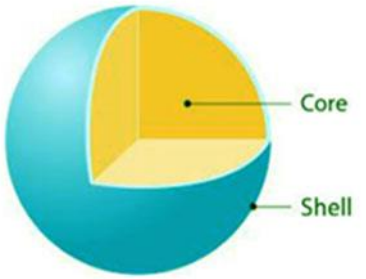

Figure 1

Encapsulated items are classified into three groups based on their size

a) A solitary hollow chamber exists within a mononuclear microcapsule.

b) Polynuclear microcapsules have several different sized chambers within the shell.

c) The active chemicals are integrated in the matrix of the matrix type microparticle. However, the internal structure of a microparticle is mostly dictated by the shell materials utilized and the microencapsulation procedures employed. [3, 19]

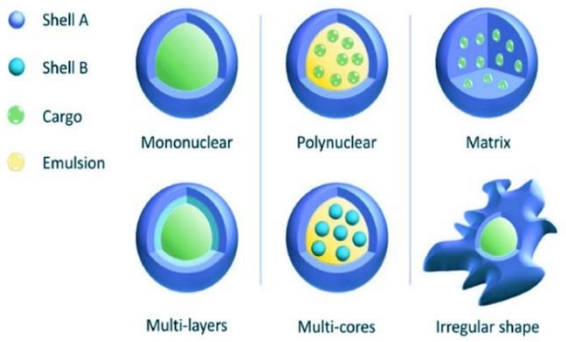

Figure 2

There is a distinction in the literature between "matrix" encapsulation and "true" encapsulation. In matrix encapsulation, the resulting particles are more accurately described as aggregates of actives in a matrix material, with a significant portion of the active lying on the surface of the particles. True encapsulation is used for processes leading to core-shell-type products.[19]

The products might be round, oblong, or irregular in shape, monolithic or aggregates, and have a single or many walls. Depicts various common capsule shapes. The capsules are made up of coated or entrapped ingredients known as active, core material, fill, internal phase, or payload (for example, fragrance compounds). The matrix or covering material is referred to as a wall, membrane, carrier, shell, or capsule. [3, 19]

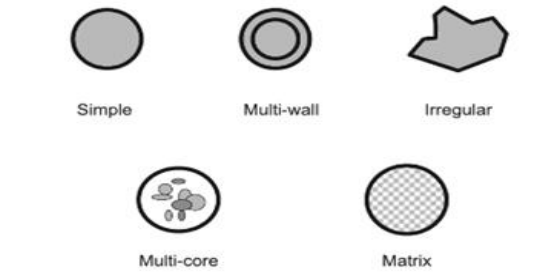

Figure 3. Morphology of microcapsules [3]

Matrix or Coating materials

Amongst the most commonly used matrix materials are:

a) Polysaccharides and sugars (gums, starches, celluloses, cyclodextrin, dextrose, etc.)

b) Proteins (gelatin, casein, soy protein,etc.)

c) Lipids (waxes, paraffin, oils, fats, etc.)

d) Inorganics (silicates, clays, calcium sulphate, etc)

e) Synthetics (acrylic polymers, poly(vinylpyrrolidone),etc.

Biodegradable polymers, both synthetic and natural, have gained popularity as carriers because to their biocompatibility and, as a result, low environmental effect. Synthetic polymers such as polyesters, poly(ortho-esters), polyanhydrides, and polyphosphazenes are examples of biodegradable polymers, as are natural polymers such as polysaccharides such as chitosan, hyaluronic acid, and alginates. [3]

Microencapsulation methods commonly used in textile

Physical methods

Spray drying, centrifugal and fluidized bed techniques, and other physical procedures are fundamentally incapable of creating microcapsules smaller than 100 m. The best chemical processes are those that are associated with simple or sophisticated coacervation and interfacial (or in situ) polymerization procedures. [20, 21]

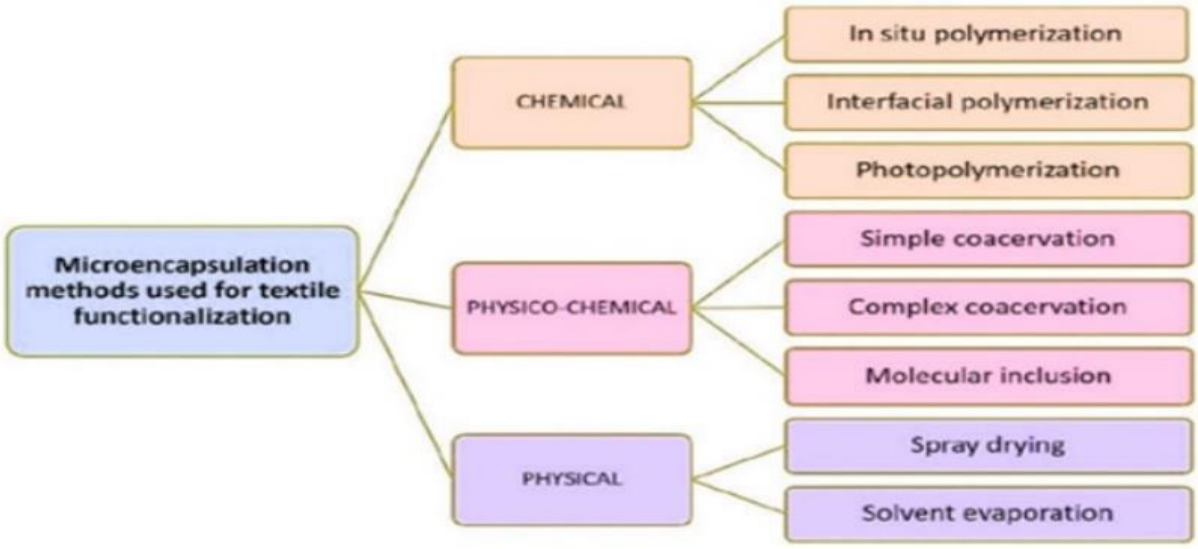

Figure 4 .Microencapsulation methods for textile functionalization [4]

Spray drying

Spray drying is the process of spraying an emulsion of shell and core material into a heating chamber with precisely controlled atomization, where the solvent quickly evaporates, resulting in capsules. The following are the stages of the microencapsulation process:

- **S**praying the emulsion into minute droplets at a constant rate with an atomizer. The previously scattered droplets are dried using hot gas.
- The capsules are collected and separated using cyclones and filters. [4]
- Spray-drying microencapsulation is a low-cost commercial technology used primarily for the encapsulation of perfumes, oils, and tastes. Core particles are disseminated in a polymer solution and sprayed into a heated chamber during this technique. As the solvent evaporates, the shell material hardens onto the core particles, resulting in poly-nuclear or matrix microcapsules. Encapsulated particles are frequently aggregated, and the usage of significant volumes of core material can result in uncoated particles. However, larger core particle loadings of up to 50-60% have been documented. Because a solvent-borne system causes unpleasant smells and environmental issues, water-soluble polymers are mostly employed as shell materials. [6]

Pan Coating

The core particle is placed in the pan, and the polymer is slowly injected into the pan, which rotates at a slower speed to guarantee appropriate coating of the core material. [4]

Air Suspension Coating

It consists of spreading the core material in a supporting air stream and coating the air suspended particles. [4]

This technique provides more control and flexibility. While suspended in an upward-moving air stream, the particles get covered. They are held up by a perforated plate with varied hole designs inside and outside a cylindrical insert. Only enough air can ascend through the outer annular region to fluidize the settling particles. The majority of the rising air (which is typically heated) flows within the cylinder, forcing the particles to climb quickly. They settle back onto the outer bed and proceed downhill to resume the cycle when the air stream diverges and slows at the top. In a few minutes, the particles travel through the inner cylinder several times. The air suspension procedure provides a diverse range of coating materials for microencapsulation. The method can apply coatings in the form of solvent solutions, aqueous solutions, emulsions, dispersions, or hot melt in equipment with capacities ranging from one pound to 990 pounds. Air suspension methods may efficiently encapsulate core materials composed of micron or submicron particles, however aggregation of the particles to some greater size is usually obtained. [6, 22, 23]

Centrifugal extrusion

For both the core and shell pieces, this system employs a concentric feed system with nozzle heads. When the active core is placed in liquid form in the nozzle's center and the polymer is introduced in melt or solution form in the nozzle's shell, vibra-

tion ensues, followed by curing activity, culminating in the formation of microcapsules. [4]

Solvent evaporation method

In the dissolved polymer volatile solution, the active core component dissolves slowly. The solvent in the solution evaporates, leaving the microcapsule behind. (9)

The procedures of this technology are carried out in a liquid production vehicle. The microcapsule coating is dissolved in a volatile solvent that is incompatible with the liquid phase of the production vehicle. In the coating polymer solution, a core material to be microencapsulated is dissolved or distributed. The core coating material combination is distributed in the liquid production vehicle phase with agitation to achieve the required size microcapsule. The mixture is then heated (if necessary) to evaporate the polymer solvent. A matrix-type microcapsule is generated when the core material is dissolved in the coated polymer solution. The liquid vehicle temperature is decreased to ambient when all of the polymer solvent has been evaporated. The microcapsules can now be employed in solution, coated on surfaces, or separated as powder. [6]

Physical-chemical methods

Coacervation The macromolecular colloid-rich coacervate droplets form a viscous microcapsule wall, which is cemented by cross-linking agents and surrounds dispersed microcapsule cores. This is a common occurrence in colloid systems. [4]

Simple coacervation: In simple coacervation, a desolvation agent is utilized to separate the phases. Complex coacervation: When two hydrophilic colloids' solutions are joined under the right conditions, complex coacervation refers to the phase separation of a liquid precipitate or phase. The solution's three phases are created, and the solvent evaporates, leaving the sheath over the core substance. [22]

Chemical methods

Polymerization occurs when the monomers in an emulsion polymerize around the droplets, resulting in a solid polymeric wall. Only the aqueous phase of the emulsion gets monomers or pre condensates during in situ polymerization. Polymerization occurs at the interface when one monomer is dissolved in water and the other in a lipophilic solvent. [4]

Emulsion and interfacial polymerization

Oil-in-water or water-in-oil emulsions (or several emulsions) can be used to create microcapsules. The actives are contained inside a monomer or polymer matrix that can be polymerised and cross-linked. After the emulsions have been broken, the microcapsules can be dried by solvent evaporation or other processes. Interfacial polymerisation happens with surface-active monomers or polymers that have been made insoluble by polymerisation or cross-linking processes. Polymerization occurs at the water-oil contact. The application of these technologies is limited because the preferred matrix or coating materials, such as polyesters, polyamides, polyurethanes, polyacrylates, or polyureas, are non-renewable or non-food grade, frequently leaving remnants of harmful monomers. Recently, polyaccaride-based systems with food-grade cross-linkers have been reported. [3, 24]

Co-crystallisation

Co-crystallisation is mostly accomplished using supersaturated sugar solutions. Sugar crystals create aggregated particles (3-30mm) that entrap guest molecules. Sugars act as an oxygen barrier, prolonging the shelf life of fragrance compounds. Because very inexpensive encapsulation matrices, such as sucrose, may be utilized, the technique is both simple and inexpensive. [3]

Inclusion Complexation

Inclusion complexation, also known as molecular encapsulation, is based on the inclusion of one active molecule into the cavity of another molecule. The most well-known systems are cyclodextrine-based. Cyclodextrines are utilized to safeguard heat-sensitive or oxygen-sensitive compounds. They are used to make hydrophobic molecules more soluble in order to lessen the volatility of fragrance chemicals. The cyclodextrin's core cavity is hydrophobic, making it appealing to hydrophobic molecules. Guest molecules are coprecipitated or cocrystallised from aqueous solution to achieve complexation.

Because of the high drying costs and the high price of cyclodextrin, obtaining large loadings from hydrophobic actives with limited solubility is a costly process. Although amylose may be utilized to generate inclusion complexes in theory, its usage is limited due to the low solubility and expensive cost of pure amylose, as well as the low specificity of high-amylose-containing starches. [3]

New technology, nanotechnology

The development of novel encapsulation technologies is time-consuming and labor-intensive, necessitating a multidisciplinary approach. Materials used for scent encapsulation, unlike foods, are not subject to strict regulation. This facilitates the usage of novel materials as materials as materials. Following that, several new developments with promise for the near future are highlighted.

Nanotechnology is a popular topic in the scientific community. The focus of research is on the

qualities that result from scaling down structural elements of materials to the nanoscale range.

Tow strategies are used to make nanostructures materials:

- Top down-break down larger structures.
- Bottom up-build from individual atoms or molecules capable of self-assemblage. [3]

Sol-gel processing

The sol-gel method was developed in the ceramic industry.It is the inorganic equivalent of interfacial polymerization encapsulation. An inorganic gel network is created during sol gel encapsulation by gelation of a sol (a colloidal solution). Metal alkoxides are the most often employed precursors because they may react and undergo the sol-gel transition in an aqueous environment. [3]

Supercritical solutions

Supercritical solutions are thick solvating gases or low-viscous low-density liquids. The most well-known and likely most intriguing candidate is carbon dioxide-based. Supercritical carbon dioxide is a kind of organic solvent. Several concepts based on supercritical fluids have been explored, including a process comparable to traditional spray-drying and fast expansion of supercritical solutions. Early approaches were limited to shell materials that could dissolve in supercritical fluids; however, a minor modification to the process widened its application to matrix materials that could swell in supercritical fluids, such as proteins and polysaccharides. The use of supercritical carbon dioxide eliminates the need for organic solvents and makes the process more ecologically friendly. [3]

Application of Microcapsules for Functional Textiles

Nowadays, one of the most significant market needs is the usefulness of textile products.Microencapsulation has been the most extensively utilized method for functionalizing textile materials since the mid-twentieth century. Using the microencapsulation method, textiles with unique enhanced properties such as medicinal textiles, antimicrobial textiles, aroma/fragrant textiles, and insect/mosquito repellent textiles are generated and changed. [4, 25-28]

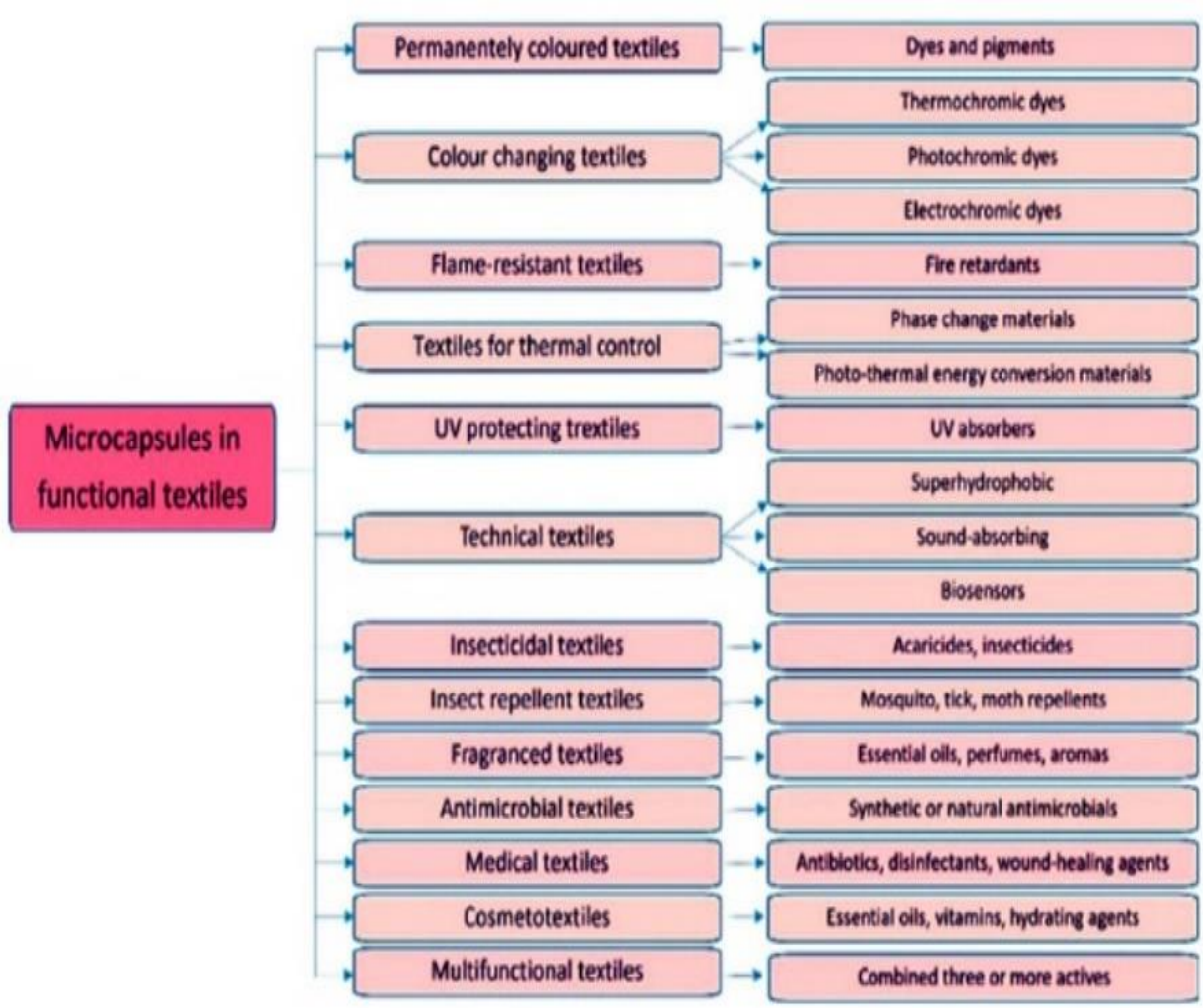

Figure 5. Microcapsules in functional textiles [4]

Aromatic nanocapsules

Fragrance/Scent finishing is a burgeoning industry that adds value and usability to textile products by integrating scent. Plant-based fragrances, such as essential oils, not only have a pleasant aroma but have also been utilized as antiseptics, anti-inflammatory agents, antimicrobials, and emotional sedatives. Aromatherapy textiles include essential oils derived from plant-based raw materials, which can assist to improve the mental and physical health of the body. Mechanical strain on the capsules during wear causes microcapsules to break, releasing the active component. Several research investigations have been undertaken in order to generate fragrance textiles. [4, 7, 8, 29, 30]

Many fragrance finishes have been applied directly to fibers and textiles, however the perfume does not persist more than two wash cycles. Microencapsulation of scents is a process that, when put on cloth, provides a longer lasting impact. This technology is often used in aromatherapy, where microcapsules can contain essential oil flavors such as lavender, rosemary, and pine, among others. This is done mostly to cure sleeplessness, headaches, and to avoid unpleasant odor. [5, 6]

Perfumes are used to accomplish three goals:

- To mask unpleasant odours of cleansing agents
- To give the message of cleanness during storage and use
- To impart a nine smell to the fabric

Encapsulation is a sophisticated method of increasing the performance of scents in washing powders, tablets, or conditioners, such as substantivity, tenacity, or durability. Evaporation, interactions with other components, oxidation, and chemical degradation all contribute to scent performance loss. Encapsulation can be used to solve a variety of challenges, including:

- Reduce the reactivity of the fragrance with the outside environment, for example oxygen, PH and water.
- Decrease the evaporation rate of the fragrance, control the release rate and provide sustained release.

- Promote the ease of handling of the fragrance.
- Prevent lumping
- Improve the compatibility with other constituents
- Convert a gas or liquid to a solid form
- Promote easy mixing
- Dilute the core material to achieve uniform dispersion in the product
- Stabilise and protect the fragrance during storage
- Reduce the losses (of top notes) during repeated opening of the packages
- Increase use levels without affecting solubility and dispersing behavior.
- Reduce loss levels in washing water and sewers.
- Extend shelf life
- Increase deposition and adhesion on textiles. [3, 8]

Using electrostatic adsorption and in situ immobilization technologies, control-released aromatic nanocapsules/cotton textiles with high wash durability and long-lasting fragrance release capabilities were created without the use of adhesives. [31] The cotton textiles were given a positive charge surface by the quaternary ammonium cationic treatment, allowing them to adsorb negatively charged aromatic nanocapsules with the core material of lavender essence and the wall material of epichlorohydrin modified cyclodextrin equally and abundantly. [32] Following that, in situ immobilization gave aromatic nanocapsules with the capacity to rapidly "grow" on the surface of cationic cotton fibers in an even and solid manner due to the mechanism of alkali solution insideoutside diffusion and penetration throughout fibers.[33]

After 120 days, the aroma of the created textiles could be discharged continually. The maximum percentage of retained essence after five wash cycles was 91.19%, which was 4.7 times that of the unimmobilized aromatic materials. The lack of adhesives in the preparation process decreases environmental contamination, and the aromatic nanocapsules solution is recyclable, both of which contribute to industrial sustainability. Electrostatic adsorption/in situ immobilization is a simple and environmentally friendly method for creating nanocomposite materials with potential applications in aromatic medical care textiles, functional aromatic home, apparel items, advanced functional materials, and so on. [34]

So far, there have been numerous conventional ways for directly fixing essence on textiles to endow the textiles with functional scent, such as immersing, cushioning, coating, printing, microwave, ultrasound, ultraviolet, and so on. However, disadvantages such as inadequate combination fastness, rapid aroma volatilization, and inability to generate the impact of long-lasting smells hamper the development of these aromatic fabrics. Microencapsulation technique might wrap the essence in a fully closed or semiclosed microcapsule, preventing aromas from fast volatilizing and extending the service life of aromatic fabrics. [32]

However, the particle size of the essence-coated microcapsules is often big, resulting in poor combination fastness and uneven dispersion across the cloth. Meanwhile, microcapsules are trapped on the textile surface by a binder that includes dangerous and hazardous substances, such as formaldehyde, posing a risk to individuals and the environment. In the absence of chemical binders, the direct load technique of aromatic nanocapsules on textiles is developed to address these issues. [34]

Cationic treatment

Cotton textiles were positively charged in this study due to quaternary ammonium cationization, allowing for the effective adsorption of negative aromatic nanocapsules. The innovative in situ immobilization technique is used to cause the alkali solution to diffuse and permeate on the cotton fabric from fiber inside to fiber outside, in conjunction with fiber wicking. As illustrated in Figure 1a, aromatic nanocapsules are chemically bound to the cotton fabric in situ at the adsorption site, avoiding self-agglomeration of nanocapsules while simultaneously achieving excellent immobilization. [35] Finally, functional textiles with nanograde aromatic materials were prepared in an environmentally friendly manner, as shown in Figure 1b, and possessed long-lasting sustained release fragrance and good wash durability, with potential applications in the fields of aromatic medical care textiles, functional aromatic household, clothing products, advanced functional materials, and so on. [34]

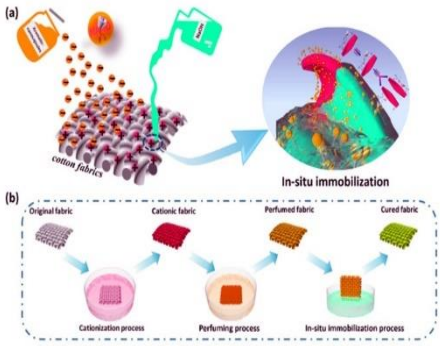

Figure 6. (a)Schematic diagrams of electrostatic adsorption and in situ immobilization of aromatic nanocapsules on cotton fabrics. (b) Flowchart of aromatic fabrics preparation [34]

Examples

The microemulsion process was used to make alginate nanocapsules containing peppermint oils, which were then applied to cotton fabric using a microwave curing procedure. To graft the aromatic nanocapsules on the cotton fibers, three types of binders were used: acrylate, polyvinyl acetate (PVA), and polyurethane (PU). [36, 37] As a catalyst, di ammonium hydrogen phosphate (DAHP) was synthesized. The fabric sample was a cured and bleached 100% cotton cloth.

Preparation of nanocapsules

Fragrant nanocapsules were created using sodium alginate for the wall, peppermint oil for the core, and Tween 20 as an emulsifier. A combination of 1.5% sodium alginate, 3 mL peppermint oil, and 0.1% Tween 20 was swirled for 5 minutes using a 200-W and 24-kHz ultrasonic wave-generating apparatus fitted with a sonotrode (3 mm in diameter). Finally, 5% calcium chloride was added to the microemulsion before continuing the sonification procedure to generate nanocapsules. [38]

A sophisticated coacervation procedure was employed to create limonene and vanillin microcapsules from chitosan/gum Arabic. Tannic acid was utilized as a shell material hardening agent. The encapsulation efficacy, microcapsule form, and release profile of two distinct emulsifiers, polyglycerol polyricinoleate (PGPR) and Span 85, were investigated. The prepared microcapsule measured between 10.4 and 39.0 m in length. Regardless of the essential oil utilized, Span 85 produced mononuclear morphology, whereas PGPR produced polynuclear morphology. The microcapsules were grafted onto the cotton fabric using an esterification procedure using citric acid, which was then heat-fixed and cured. [39]The finished textile exhibited antibacterial properties. [40]

In several investigations, Vetiver oil microcapsules were created for use on organic cotton knit fabric. The pad dry curing method was used to attach microcapsules to the organic cotton knit fabric, and the interfacial polymerization procedure was used to create microcapsules containing vetiver essential oil. [41] Organic cotton knits finished with microcapsules by pad dry cure process revealed the highest zone of inhibition when compared to knitwear completed by exhaust. Multiple washing cycles were utilized to assess the antimicrobial activity of the final samples, and it was discovered that knits finished with the pad dry cure approach had a zone of inhibition even after the 20th wash and had better aroma retention than knits finished with the exhaust method of application. The chemical-free vetiver microencapsulated organic cotton knits feature multi-functional properties that make them excellent for medical and healthcare textiles. [41-43]

To microencapsulate methyl central ketone (MCK) with polyurethane urea (PUU) polymers, interfacial polymerization was utilized. The capsule shell's principal component, PUU (isocyanate/PEG-400/polyamine) mole ratios (5.4/3.0-5.5/1.5-3.9), was synthesized in 240 minutes at 80 oC. The encapsulation efficiency of the created microcapsules, CMK-PUU microcapsule release at normal temperature, microcapsule shell degradation at high temperature, and adhesion durability were all examined when fixed on cotton, polyester, silk, and nonwoven fabric. [24]

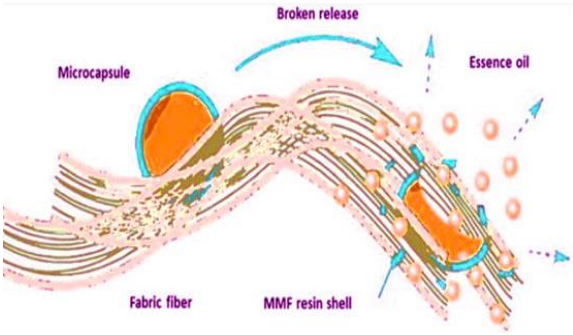

Figure 7: (Release of aroma microcapsules under external force)

Interfacial polymerization was employed in several research to manufacture polyurethane-urea microcapsules with fabric softener fragrances as active agents, lengthening the release rate and boosting the fragrance's endurance. It was also revealed that increasing the emulsion's stirring rate induced microcapsule breakage, which might result in the aroma being released faster. [44] The agglomeration rate increased throughout the emulsion process. According to optical and SEM data, increasing the stirring rate during the emulsion stage resulted in smaller particle size microcapsules, however it has an unfavorable influence on their form at a particular point. [24]

Some of the reported works on the microencapsulation of flavors and fragrances and applications in the textile industry: [38]

Antimicrobial Textiles

Microbial growth on textiles can cause unpleasant smells, skin irritation, discoloration, and other problems. [45] Microbes flourish in situations with high levels of moisture and cellulose, such as cotton garments. Antimicrobial finishing is a chemical treatment that kills or inhibits the growth of microscopic organisms. [46-53]

In certain investigations, they used the basic coacervation process and butane tetracarboxylic acid (BTCA) as a binding agent to create Aloe Vera microencapsulation with cornstarch in cotton nonwoven fabric. The microcapsules, in conjunction with a simple coacervation method, fully met the objec-

tives. This assumption is supported by micrography, thermograms, o.w.f., and Tw indices, which demonstrate that the finishing adheres to the substrate. [54]

In previous investigations, the Box Behnken experimental design approach was utilized to optimize the combination of antibacterial and mosquito repellent treatment on woven cotton fabric utilizing microencapsulated Coleus aromaticus. The shell material for the microcapsules was gum acacia, while the inner material was Coleus aromaticus leaf extract.[55] The capsules were applied to the Cotton fabric using a pad-batch method. Three process variables have been optimized: microcapsule concentration (g/l), BTCA concentration, and curing temperature. The antibacterial and mosquito repellent properties of the treated fabrics were evaluated. Following that, a polynomial equation was developed to account for both antibacterial activity and mosquito repellency behavior. [56] RSM analysis was used to explore the impacts of each process variable on the answer. The best process parameters were 40 g/l microcapsule concentration, 67.5 g/l BTCA concentration, and 116°C curing temperature. The total desirability coefficient was found to be 0.792n. [24, 55]

Core material	Wall material	Encapsulation method	Application in textiles	
			Treatment method	Fabric
Migrin oil	Melamine and formaline	In situ polymerization	Printing	Cotton
Forest-shower fragrant solution	Poly(L-lactide)	Interfacial precipitation	Printing	Cotton
Mexican daisy extracts and neem oil	Gum acacia	Separation/coacervation	Pad-dry cure	Cotton
Mint flavor	Melamine formalin	No information was supplied by the provider	Impregnation or bath exhaustion	Cotton
Limonene	Polyurethane/ urea	Interfacial polymerization	Pad-dry cure	Wool/ polyester
Ocimum sanctum oil	Alginate–chitosan	Gelification	Pad-dry cure	Cotton
Eucalyptus and sandalwood oils	Chitosan	Emulsion	Pad-dry cure	Cotton
Citrus unshiu	Melamine-formaldehyde	In situ polymerization	Pad-dry cure	Cotton
Lavender	Melamine-formaldehyde	Commercial	Padding and bath exhaustion	Cotton

Figure 8

Other experiments used an interfacial polymerization technique to create microcapsules from Palmarosa oil, which were then finished on organic knitted fabric using exhaust and pad dry curing procedures. In the final organic knit, the influence of laundering on antibacterial efficacy and smell intensity was studied. Palmarosa microcapsules exhibited a higher TGA and less weight loss at higher temperatures than pure oil, however their form was quite uneven due to manufacturing conditions. [46] The antibacterial activity of the final samples was tested several times, and the findings revealed that knits completed with the pad dry cure technique had a zone of inhibition even after the 20th wash, as well as superior aroma retention than knits finished with the exhaust method of application. As a consequence, the Palmarosa microencapsulated organic cotton knits are free of hazardous chemicals and offer multi-functional properties suitable for medical and healthcare textiles.[46, 57]

In other research, they used citric acid as a green binding agent to microencapsulate cellulosic fibers to confer antibacterial properties. Coacervation was employed to encapsulate an essential oil mixture, with chitosan serving as the wall material and sodium hydroxide serving as the hardening agent. [58] The size of the produced microcapsules ranges between 12 and 48 m. The attachment of the produced microcapsules to the surface of cotton textiles was shown using attenuated total reflectance-Fourier Transformed Infrared (ATR-FTIR) spectroscopy, optical microscopy, and scanning electron microscopy (SEM). [47]

Other investigations employed the complex coacervation technique to make LO microcapsules with chitosan and gum arabic wall components. Lime oil microcapsules were effectively manufactured employing a complex coacervation technique that included gum Arabic and chitosan wall components. After microencapsulation, the antioxidant and antibacterial properties of lime oil were pre-

served. The antibacterial activity of lime oil microcapsules was proven against all four bacterial species tested. Furthermore, the cytotoxic action of unencapsulated lime oil is obscured by microencapsulation. [59, 60] To successfully embed the created lime oil microcapsules into the cotton fabric, succinic acid was employed as a binder. The lime oil-infused cotton fabric displayed high antibacterial activity after mechanical crushing of its microcapsules. The cloth containing lime oil microcapsules retained its microcapsules and antibacterial function even after moderate washing. [24, 38]

Insect/Mosquito Repellent Textiles

The mosquito repellent textile product was newly developed, and the preparation procedure includes applying mosquito repellent chemicals to textile fabrics. [61-63] The mosquito is a major arthropod vector of diseases such as malaria, yellow fever, Rift Valley fever, dengue fever, and arboviral encephalitis. These infections endanger human and animal health and cause significant death globally.

Repellents play an important role in numerous anti-mosquito products, and while they are not commonly used, they are required raw materials in the manufacturing of different anti-mosquito products. To offer mosquito protection, insect repellents such as N, N-diethyl-metatoluamide (DEET) can be applied directly to the skin or in combination with permethrin-containing fabrics. [61]

In other research, an ionic gelation method was employed to generate andrographolide-loaded sodium alginate microcapsules, which were subsequently exhausted onto a bamboo/cotton fabric. Mosquito repellency of microcapsule-finished textiles was 94%, compared to 96% for directly finished fabrics. After 30 washes, the repellency of microcapsule-finished textiles was reduced to 52% and 40%, respectively, for directly finished materials.[62]

In additional experiments, the ionic gelation technique was utilized to manufacture mosquito repellent microcapsules from three wall materials: Acacia arabica, sodium alginate, and Moringa oleifera gum, as well as a combination of three core materials: grapefruit oil, cypress oil, and thyme oil. Even after 30 washing cycles, the Moringa oleifera gum microcapsules preserved 60% mosquito repellency. [24, 64]

Mosquito repellency test (cage test)

The mosquito repellent test was completed. Cotton cloth that has been microencapsulated. [63] Hundreds of mosquitos were permitted within a 30x30x30 cm cage with a temperature of 25 3°C and a relative humidity of 65 5%. The test cloth was wrapped around the subject's arm and subjected to mosquitos. The occurrences of mosquito landings were measured after 2 minutes, 5 minutes, 10 minutes, 20 minutes, and 30 minutes. The % reduction in the number of mosquitos landing on the treated sample relative to the control sample was used to quantify mosquito repellency. [26-28, 65-68]

$$\%\ Mosquito\ repellency = \frac{C - T}{C} \times 100$$

where C is the number of mosquitoes collected from the control sample and T is the number of mosquitoes collected from the treated sample. [64]

Medical textiles serve a number of functions, including first aid, therapeutic, pharmacological, and hygienic applications. Bandages, gauzes, and tissue culture medium are examples of medical textiles, as are body implants such as skin, artificial heart, blood artery, and heart valve. [69]

Use ecofriendly algal volatile organic compounds to impart wound healing capabilities to cotton fibers, resulting in a bandage (VOCs). VOC levels in Digenea simplex, Lurencea papillosa, Galaxurea oblongata, and Turbenaria decurrens were 0.52, 0.9, 0.87, and 0.62% (v/w), respectively. These VOCs and their microencapsulated (VOM) forms were finished onto cotton textiles using a standard pad-dry curing technique, with sodium alginate (SA) as a shell wall material. The VOCs of each alga were extracted and analyzed using gas chromatography coupled with mass spectrometry (GC-MS). The findings demonstrate the diversity and remarkable differences in volatile composition among the four algae, as well as the identification of 125 volatile compounds. The wound-healing properties of the finished fabrics were evaluated. Textiles finished with VOCs microcapsules (VOMF) performed better than textiles treated with VOCs (VOF) and were nearly as effective as fabrics finished with mebo-ointment (standard medicine) (MoF). The volatiles in the four algae range in kind and volume, which might explain the differences in VOC efficiency. As a result, the technique of generating encapsulated VOCs for use in textile wound healing is low-cost, simple, reproducible, and scalable. [70]

Encapsulated in a sodium alginate film using glycerol as a plasticizer were chamomile blue, tea tree, lavender, lemongrass, peppermint, elicriso italic, lemon oils, cinnamon, and eucalyptus oils. The composite wound dressing film indicated that the majority of EOs inhibit C. Albicans growth. Antimicrobial qualities are found in peppermint, lemongrass, and cinnamon oils. [24]

PCM (Phase change materials)

PCMs are energy storage materials that have significantly better thermal energy storage densities than sensible heat storage materials and may absorb or release enormous amounts of energy at a steady temperature by experiencing a phase shift. [71]

Latent heat storage is a very effective method of storing thermal energy. The latent heat storage method, as opposed to the sensible heat storage approach, gives substantially better storage density with a lower temperature differential between storing and releasing heat. During a heating process, every substance absorbs heat while its temperature rises continually. Through a reverse cooling process, the heat held in the material is released into the environment.[72] The material temperature steadily drops during the cooling process. When comparing heat absorption during the melting process of a phase change material (PCM) to that of regular materials, a PCM absorbs significantly more heat. A paraffin-PCM, for example, absorbs roughly 200 kJ/kg of heat during the melting process. The heat collected by the paraffin during the melting process is released into the surrounding region during a cooling process that begins at the crystallization temperature of the PCM. When the heat storage capabilities of textiles and PCM are compared, it is clear that putting paraffin-PCM to textiles may significantly increase their heat storage capacities. [26, 73-85]

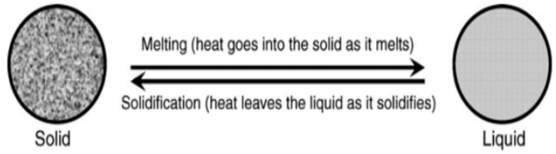

Figure 9 Schematic representation of phase change process.

PCM-microcapsules

Microcapsules with walls less than 2 mm thick and a diameter of 20-40 lm are beneficial in fiber applications. These containers' main contents are released under regulated settings to fit a specific purpose. [64]

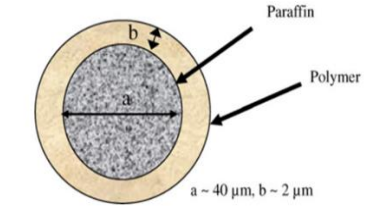

Fig. Microencapsulation: Paraffinic PCM core material individually with a hard polymeric shell.

Figure 10

Applications of PCMs incorporated textiles

Textile phase change materials (PCMs) respond to the thermal regulating functional performance of PCM garments by changing their aggregation state across a predetermined temperature range. Apparel, blankets, the medical profession, insulation, protective garments, and many more applications are possible using phase change textiles. The following is a synopsis of PCM applications in textile areas. [86]

Space

The method employs phase change materials, which were originally designed for use in space suits and gloves to keep astronauts warm while working in space. Astronauts are kept comfortable in orbit thanks to phase-change materials. [86, 87]

Sports wear

Phase change materials (PCM) are currently used in consumer items, in addition to their initial usage in space suits and gloves. Clothing materials with thermo-regulating qualities are frequently employed to improve the thermal performance of active-wear clothes. The thermoregulating effect offered by these fabrics might be attributed to the use of PCM. The PCM amount applied to the active-wear garment must be matched with the degree and duration of the activity for which the garment will be used. While participating in a sport, active clothing must offer a thermal balance between the heat generated by the body and the heat discharged into the environment. The heat created by the body during athletic activity is frequently insufficiently discharged into the environment, creating thermal stress. as phase change materials are included into sportswear, the wearer's excessive body heat increases during physical activity and is absorbed by the encapsulated phase change materials and released as necessary. Snowboard gloves, underwear, active wear, ice climbing, and cycling and running underwear are a few other examples of PCM uses in sportswear. [64]

Medical applications

As phase change materials interact with the microclimate around the human body, they adapt to temperature fluctuations induced by changes in activity levels and the external environment. As a result, textiles treated with PCM microcapsules might be used in surgical clothing, patient bedding materials, bandages, and goods used to manage patient temperatures in intensive care units. PEG-treated cloth has the potential to be beneficial in medical and hygiene applications requiring both liquid conveyance and antibacterial qualities, such as surgical gauze, diapers, and incontinence products. Heat-storage and thermo-regulated textiles can keep skin temperatures comfortable, allowing them to be used as a bandage as well as for burn and heat/cool therapy. [64]

Water repellency

Water-repellency is a feature of some natural or manufactured materials that prevents water from adhering to them. Drops roll off these solids extremely readily and bounce back when they hit them. [49, 88-94]

Sol-gel

The initial experiment was designed to create hydrophobic sols for use. An acidic hydrolysis was used to create simple tetraethoxysilane-based alcoholic sols. As additives, several aliphatically modified alkoxysilanes were investigated. [95] These alkoxysilanes were changed with increasing length linear alkyl chains. Before drying, the various sols were applied to a polyester fabric using a simple dipping method. A DuPont test was performed to assess the repellence of these variously modified materials. While the gray fabric produces a DuPont grading of zero, the sol-gel treated samples produce significantly better results. [96] The repellence is roughly anticipated to increase with the length of the alkyl chain of the additive employed, as seen by rising contact angles of water recorded for coatings on glass. [97]

Coatings based on SiO2-sols are being developed for the simultaneous application of hydrophobic and antistatic characteristics, specifically for textile finishing. The coatings provided may resist water while also absorbing relatively large volumes of water/water vapour in the deeper areas of the coating layers. If SiO2-sols are created with a mixture of hydrophilic and hydrophobic additives, the findings support the idea of the formation of a hydrophobic interface solid/air and a more hydrophilic bulk. [97]

Using polymer

In the other investigation, the eri silk fabric was treated with nano silica for a semi-durable water repellent finish using the pad dry cure process. The particle size of the silica nano particles generated was determined to be less than 300 nm. The application of nano silica increased the water contact angle from 87.5 to 112.9, while the addition of 1.0% silicone polymer increased it to superhydrophobic levels. After 60 minutes of storing 10 droplets of water in the cloth, it was discovered that 7 drops remained unabsorbed for 7.5% nano silica alone and 8 drops for 7.5% nano silica plus 1.0% silicone polymer. [98] This suggests that the inclusion of polymer considerably improved the water repellency of nano silica. The conclusions are further supported by spray test results. The application of nano silica did not impact the whiteness index of the eri silk fabric, but it did produce an increase in bending length and a decrease in air permeability and tenacity at higher concentrations. Taking water contact angle, water absorbency test, and physico-mechanical properties into account, 5.0% Nano Silica Polymer obtained super hydrophobicity (contact angle-151.9), and no further significant improvement in contact angle was found after increasing the silica concentration to 7.5%, the 5.0% silica concentration is considered the optimum concentration. [97]

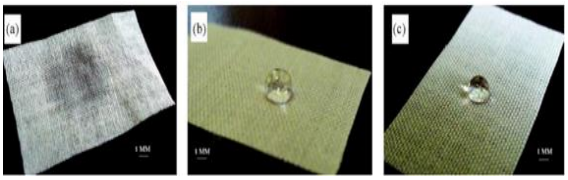

Figure 11. Wetting of cotton fabric samples: complete wetting of untreated textile (a): water drop on the textile treated with the hydrophobic agent (b): water drop on the superhydrophobic surface of the textile treated with the hydrophobic agent (c). The scale bar on all the images is 1mm.

Conclusion

Microencapsulation technique encapsulates a chemical inside a tiny sphere known as a microsphere/microcapsule, with an average diameter ranging from 1 mm to several hundred micrometers. Microencapsulation technology is a powerful approach for controlling the release qualities of active components that extend the usefulness of smart textiles and include a wide range of active elements such as flavors. Depending on the final usage of encapsulated items, these microcapsules release their contents at the proper moment utilizing diverse release mechanisms. This technique has been employed in a variety of industries, including textiles. This review study focuses on the fundamental causes for microencapsulation, essential microencapsulation processes, and applications of microencapsulated goods in many industries.

Conflict of Interest

There is no conflict of interest in the publication of this article

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