164 Egypt.J.Chem. **Vol. 63**, No. 6. pp. 2177 - 2184 (2020)

Egyptian Journal of Chemistry
http://ejchem.journals.ekb.eg/

Applications of Nanotechnology and Advancements in Smart Wearable Textiles: An Overview

Ahmad Salman[1], Fatma A. Metwally[1], Manal Elbisi[2], Ghada A.M. Emara[3*]

[1] *Textiles Dept., Faculty of Applied Arts, Helwan University, Egypt.*
[2] *Cellulosic Fibers Dept., National Research Center, Egypt.*
[3] *Ministry of Trade & Industry, Egypt.*

NANO technology has been a core of many research work for the past fifty years. Applications of nanotechnology in textiles field have increased such products value, and made these textiles as a very important part of smart inventions. Durability, comfortability, hygienic properties, UV protection, energy saving and many other properties have been achieved through using the application of nanoparticles in textiles weather through coating or encapsulation or other methods. (PANI)/polyacrylonitrile (PAN) nanofibers, silver nanoparticles, single/multi-walled-nano carbon tubes (SWCNT/MWCNT) and Ag, Au and Cu nanoparticles have been used in smart and smart wearable textiles such as stretchable textiles and wearable solar textiles, triboelectric nano-generator and one-piece self-power/self-charging power textiles. Smart wearable textiles are a result of the combination between nanotechnology and smart textiles which will be the next trend of textiles research.

Keywords: Nanotechnology applications, Smart wearable textiles, Stretchable textiles, Self-power/self-charging power textiles, Triboelectric nano-generator, Wearable solar textiles.

Introduction

More than fifty years ago, nanotechnology was defined as the utilization of structures with at least one dimension of nanometer size for the construction of materials, devices or systems with novel or significantly improved properties due to their nano-size.

For the past fifty years, nanoparticles were commonly used in several commercial products specially in textiles industry due to their large surface area-to-volume ratio and their high surface energy, thus the applications of nanoparticles had imparted different properties to fabrics which improved fabrics performance.

Nanotechnology had been applied in textiles commonly through coating and padding methods in order to have such effective properties that were not exist as antibacterial/antimicrobial properties, water repellency, antistatic, photocatalytic properties and finally smart wearable textiles.

Several applications of nanotechnology in textiles and their extra effective imparted properties are highlighted in this paper.

Nanotechnology Applications in Textiles

Antibacterial textiles

The term of Anti-microbial was created and is being searched and developed due to the continuous awareness of disease transmission and frequent infection that is one of the main leading causes of malignant diseases [1]

Silver nanoparticles (Ag NPs) are known the most common antimicrobial and antibacterial treatment over the conventional antibiotics. Silver ions has been recognized as a very strong antimicrobial agent due to their special characteristics as long antimicrobial strength over

*Corresponding author e-mail: ghd_emara@yahoo.com.
Received 14/10/2019; Accepted 3/11/2019
DOI: 10.21608/ejchem.2019.18223.2112

time and also it doesn't induce resistance in the microorganisms.

The antimicrobial action happens when the silver ions interacting with phosphorous moieties in DNA which causes an inactivation of DNA replication. Silver ions can also interact with the sulfur containing proteins (-SH) of enzymes in the microorganisms. This interaction forms an (-Sag) linkage with the enzyme which effectively blocks the enzyme activity.

Also, researchers found that the aqueous extract of the shoots of Conocarpus erectus L. (Combretaceae family), was found to be rich in tannins,flavonoids and other phenolics and showed good inhibitory activity against all tested Gram positive bacteria [2-5].

A novel antibacterial textiles treatment has been investigated which is nano boron powders treatment wither in de ionized water (Dl) water or as a textile coating.

Boron nanoparticles has been investigated to effectively limit the bacterial growth of both gram-negative and positive species with no stimulation to initiate the antibacterial action. It also changes the wettability and surface charge of the textile material with a variable antimicrobial response to the different species. [6] ZnO nano-particles has been used for multifunctional textiles as antibacterial activity, and UV protection with considering the cytotoxicity limitation.

It was found that ZnO nano-particles with a range around 1045– nm particle size exhibited a reasonable antibacterial activity against Gram positive and Gram negative bacteria. Also, recent research studied the using of copper nanoparticles and magnetic nanoparticles synthesis from lemon grass plant extracts as an antimicrobial treatment. Results showed that both copper nanoparticles and magnetic nanoparticles synthesis from lemon grass plant have an effective action against microbes [7-9]

However, textile treatments of molecules and atoms in nanoscale has provided a novel and unique action that inhibits enzyme functions and inactivates DNA replication which leads to a perfect anti-microbial and anti-bacterial action.

Water repellent Textiles

Highly water repellent textiles are obtained by using "lotus effect" that provides ultra-hydrophobic surface that shows a water contact angle greater than 150º C. [10]

Fabrics water repellency is obtained by creating what is called" Nano-whiskers". Nano-whiskers are about 1/1000 of the size of a typical cotton fiber. These whiskers create peach fuzz effect on the fabric as the spaces between whiskers are even smaller than the size of the typical drop of water but larger than the water molecules which leads to remain water at the top of whiskers and above fabric surface with a permanent performance while maintaining breathability and providing stain resistance in the same time. [11]

However, Nano-whiskers, Nano sphere impregnation, and the combination of TiO_2, ZnO, Fe_7O_3 and hydroxylapatite nanoparticles are demonstrated to improve fabrics' water repellency by replicating hydrophobic behavior to produce water and/or stain resistant fabrics. [2]

Also, a new approach of CAO/TDI adduct was synthesized by reacting 2,4-toluene diisocyanate (TDI) with castor oil (CAO) in a molar ratio of 70%, respectively, at 100°C for 90 min examined as a water-repellent as well as an antibacterial finish for cotton/polyester fabric [12]

UV resistant Textiles

Textiles have been the best areas of nanotechnology applications; these applications aim at producing fabric with different functional performance. UV resistant textiles using nano technology have attracted many scientists to develop many other fields as architecture.

As a fact; light scattering predominates at approximately one-tenth of the scattered light wavelength. According to Rayleigh's theory light scattering is inversely proportional to the wavelength, so, a particle size of about 20-40 nm is needed to effectively scatter UV radiation ranges from 200-400 nm wavelength accordingly. [11]

Zinc oxide found to have very unique photo-catalytic, electrical as it is semiconductor and piezoelectric, electronic, optical, dermatological and anti-bacterial properties as it is bio-safe and biocompatible. [13]

ZnO nano-particles with a range around 1045– nm particle size exhibited a good UV protection with a reasonable increase in UVA and UVB blocking values. [7]

Also, nano-sized zinc oxide, titanium dioxide and a part from titanium dioxide and zinc oxide nano rods of 10- 50 nm in length are found to be more effective in scattering and absorbing UV radiation and are thus better to provide a perfect UV protection when applied to cotton fabrics. This protection due to the larger surface area per unit mass and volume of nanoparticles which enables such treatments to penetrates into yarn and fabric interstices. [14]

However, TiO_2 and ZnO nanoparticles found to provide textiles several unique properties as UV protection, stain resistance and water repellency as shown in Figure (1).

Self Cleaning Textiles

There is a novel concept of textile called self-cleaning textiles that can be cleaned itself without any laundering action or even can be easily washed and maintained improving its performance in terms of energy and resources consumption.

Nano structured surfaces can reduce the contact area between textile and dirt particles which enables to overcome the problems of user's comfort and product value's reduction.

Nano crystalline TiO_2 photo catalytic found to be able to destroy organic materials by solar irradiation, also it reduces the maintenance cost of textile products including water, detergents consumption and temperature required to remove persistent stains.

However; recent research work studied the use of silver-titania nanoparticles which found to enhance fabrics' self-cleaning and anti-bacterial actions. [16-18]

Moreover; cotton polyester blended fabric treated with the nominated dialdehyde polysaccharide (DAPS, 10 g/l) along with the reactant resin (DMDHEU, 50 g/l), Ag- or TiO2-NPs as active ingredients (20 g/l) and ammonium persulfate catalyst (5 g/l) using the padding method demonstrated a remarkable improvement in their antibacterial efficacy, UV-blocking ability, self-cleaning capacity, and surface roughness functionality without adversely affecting fabrics resiliency [19]

Photo catalytic Textiles

The band gap of textile material specially the formed free radicals are the key of the photocatalytic activity. The different semiconductors as TiO_2, WO_3, CeO_2, CdS and ZnS have been widely used for the photocatalytic oxidation of chemicals.

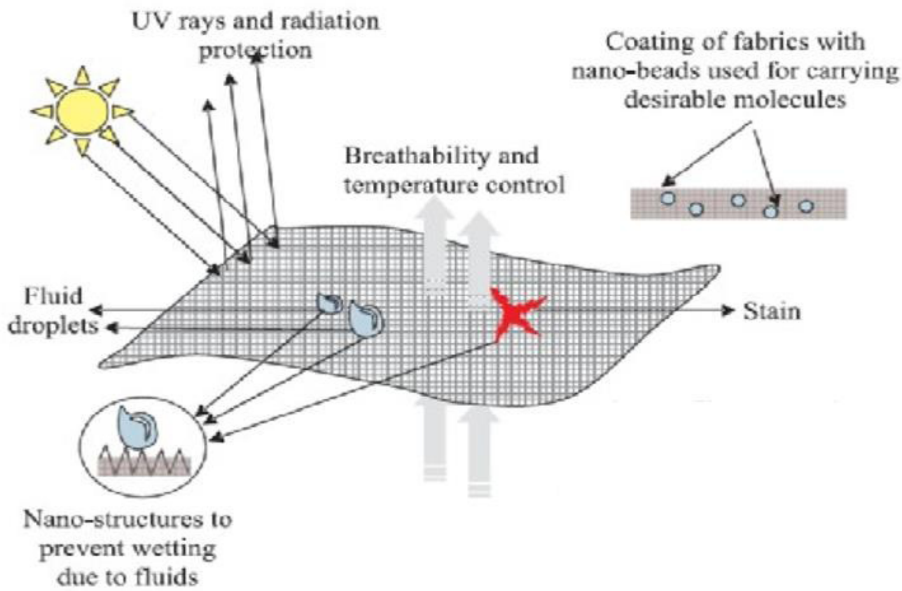

Figure (1) several unique properties provided by TiO_2 and ZnO nanoparticles. [15]

TiO_2 nanoparticles because of its non-toxicity, chemical and photo stability lower cost and higher efficiency were known as the reliable choice to achieve the photocatalytic activity of textile materials.

It was found that the band gap energy of N-TiO_2 reduction to 2.98 eV increases its photocatalytic activity induced by visible light besides its high surface wetting and visible light absorption properties that provides an effective self-cleaning action.

Moreover, using nano crystalline titania-zicronia (TiO_2-ZrO) composite have been found to have an effective photocatalytic action for textile materials treatments.

Thanks for multi-walled carbon nanotubes (MWNTs); color degradation of textile materials was enhanced. ZnO/NiO coated (MWNTs) showed an enhanced efficiency of photo-degradation activity in both UV and visible light regions. [20-22]

Smart Wearable Textiles

Energy harvesting, physical sensing and gas sensing are measurements that have been developed using nanotechnology based smart textiles. To directly monitor vital signs; an enhanced sensing system has been developed using a smart textile fabricated with a simple dip coating method with a layer of poly(3,4-ethylenedioxythiophene) polystyrene sulfonate (PEDOT:PSS) coated textile and poly tetra fluoro ethylene (PTFE) under foot stepping, and a height-varying multi-arch strain sensor with a large strain sensing range from 10% to 160%. This arch-shaped strain sensors mounted on human fingers is demonstrated to monitor hand gestures for America sign Language interpretation and robotic hand control in addition to four different located textile-based sensors that are employed to track human activities. [23]

Another achievement of stable structure, excellent mechanical properties, high gas sensing performance and handling convenience has been applied for the development of wearable smart textiles. It is a conductive polymer based single yarn consisting of core-sheath polyaniline (PANI)/ polyacrylonitrile (PAN) nanofibers that fabricated by combining a novel electrospinning method with in-situ solution polymerization process. The PAN/PANI uniaxial aligned coaxial nanofiber yarn (UACNY) was utilized to construct an ammonia (NH_3) sensor. Nanofibers offered a high surface area for the free diffusion of (NH_3). This yarn-based sensor represented an excellent stability for (NH_3) detection, and possessed a robust mechanical strength and flexibility. An excellent one-way charge carrier transfer for effectively unidirectional transmission of electrical signals was represented which both endowed the yarn sensor excellent sensitivity and fast response/ recovery upon exposure to (NH_3) of 10-2000 ppm at room temperature. [24]

A low-temperature screen-printable piezoelectric nano-composite film on flexible plastic and textile substrates was developed involving silver nanoparticles addition to the nano-composite material and using an additional cold isostatic pressing (CIP) post processing procedure. This was applied in harvesting mechanical energy from a variety of textiles under compressive and bending forces. The maximum energy density of the enhanced piezoelectric material under 800 N compressive force and under bending was found to be $34 J/m^3$ and $14.3 J/m^3$ on kermel and cotton textiles respectively which is a potentially useful amount of energy. [25]

Now, single/multi-walled-nano carbon tubes (SWCNT/MWCNT) and Ag, Au and Cu nanoparticles are being used as an electronic textile (e-textiles) basic yarn materials with several cross-sectional areas as coated, shelled, tri-lobal, twisted or sandwiched forms. This technology is applied in textiles field as pressure sensor that reliefs post-medical operational health risk hazards, textiles headband for facial EMG, knee sleeves, flex sensor and warmX vests.

Also theses e-textiles are also used in military fields in enemy detection or in facing biochemical threats. In medical field, there is "biodegradable smart shirt" that is designed to monitor vital signs and heartbeats or palpitation rates.

Smart wearable textiles have been introduced to fashion articles as industrial clothing division (ICD+ jacket) with fabricated embroidered textile keypad and many other applications that can easily perform multiple functions like mobile connection and MP3 player or geosynchronous, or geostationary, earth orbit (GEO-navigation). [26]

Another application of wearable textiles is using nanotechnology in stretchable textiles and wearable solar textiles. stretchable textiles (STs) that have great energy storage capacity and excellent conductivity. The new NiCoP nanoparticles coated spandex textiles are providing perfect conductive and electrochemical performance. [27]

A wearable ultra-light weight polymer solar textiles is obtained. It is based on transparent electronic fabrics (e-fabrics) with a structure of polyester/Ag nanowires/graphene core-shell that have been used as anodes as shown in Figure (2). The e-fabrics is blade-coated by the anode buffer layer and the heterojunction layer. These solar textiles showed a power conversion efficiency of about 2.27%, a low areal density of about 5.0mg/cm^{2,} good endurance against mechanical deformations and high compatibility with clothing. [28]

Triboelectric nano-generator which is a self-powered, feasible solution to convert mechanical energy into electricity became also one of nanotechnology applications in smart textiles. A composited fabric with flexible functional elastomer layers (FEL@CF) is now used as a negative tribomaterial in triboelectric nano-generators (TENGs). This FEL@CF TENGs can power for wearable electronics by harvesting biomechanical energy and operate in dual electrodes mode (DFEL@CF TENGs) or single electrodes mode (SFESL@CF TENGs). A shown in Figure (3); this technology is applied in power gloves that can contact with various daily-used objects for human motion energy harvesting. FEL@CF TENGs have excellent stability even under harsh and complex conditions. [29]

Recent researches has developed the direct printing of e-textile composed of core-sheath fibers using carbon nanotubes (CNTs) as a

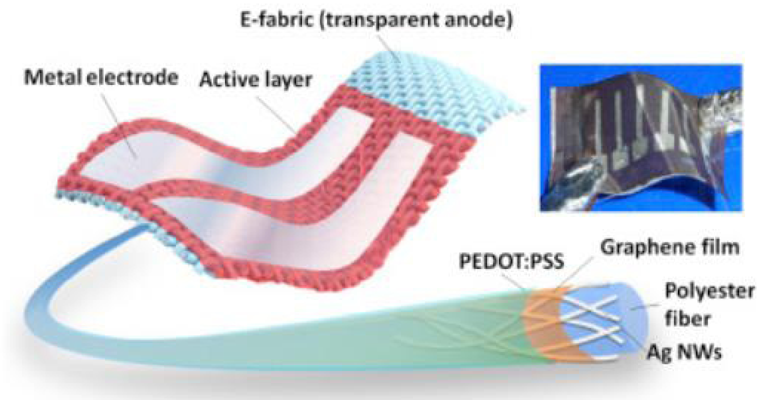

Figure (2) shows Wearable Solar Textiles. [28]

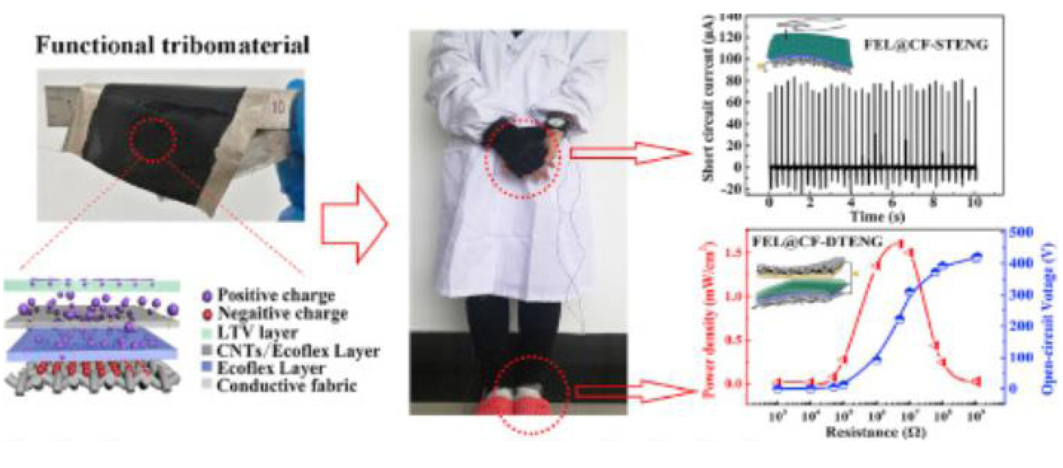

Figure (3) shows FESL@CF TENGs. [29]

conductive core, silk fibroin (SF) as a dielectric sheath and a fabricated CNTs@SF core-sheath fiber-based smart pattern by employing 3D printer that is equipped with coaxial spinneret which enables printing on textiles for various purposes. The fabricated CNTs@SF core-sheath fiber-based smart pattern is used as triboelectricity nano-generator textile. This smart textile can harvest biomechanical energy and achieve power density as high as 18 mW/m^2. This technology may lead to large production of self-sustainable e-textiles with integrated electronics. [30]

CNTs@SF core-sheath fiber-based smart pattern is shown in Figure (4)

Another application of nano technology in smart textiles is the one-piece self-power/self-charging power textiles (SCPT). This novel SCPT consists of a fabric triboelectric nano-generator (FTENG) and woven super capacitor (WSC). The SCPT is shown in Figure (5) [31]

Conclusion

Nanotechnology have introduced profitable functions specially in textiles field. Through increasing comfortability, hygienic properties, durability and intelligence; the value of textiles have been economically increased specially when applying nanotechnology in smart textiles which imparted unique functions to textile materials. The previous mentioned applications and many other ones of nanotechnology in textiles permits overcoming limitation of the conventional techniques, as a result; smart wearable textiles have been invented and are being developed. Moreover, the combination of nanotechnology and smart textiles would be a global trend of the next few years.

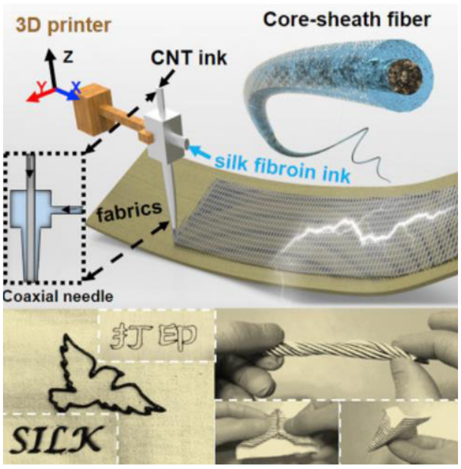

Figure (4) CNTs@SF core-sheath fiber-based smart pattern. [30]

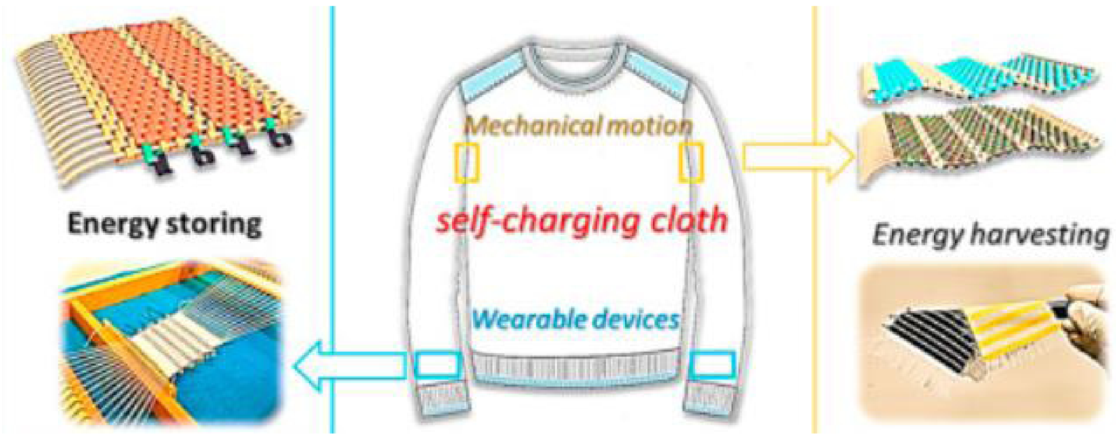

Figure (5) shows the novel SCPT [31]

Future Vision

Nanotechnology is going to be the most trending area of scientific development that promises 'more for less'. It could offer chances to create smaller, cheaper, and lighter products that can do more beyond the conventional functions using less raw materials and consume less energy. A wide application of nanotechnology in the field of smart textiles is expected in order to obtain an extra complex functions that were not existing or imagined. New-generation of human organs implants could be achieved and became more 'body friendly' just because having a nanoscale topography that encourages acceptance by the cells in their vicinity, or even combine smart textiles scaffolder with nanoparticles to develop such implants.

References

1. A.P.S Sawahney et al., "Modern Applications of Nanotechnology in Textiles", Textile Research Journal, (78) 8, pp. 731-739 (2008)

2. A. A. Hebeisha, A. S. Alya, c , M.A. Ramadana, M.M. Abd El-Hady a, A.S. Montaser∗a and A.M. Faragb" Establishment of Optimum Conditions for Preparation of Silver Nanoparticles Using Carboxymethyl Chitosan", Egyptian Journal of Chemistry, (56), 3, pp. 241- 254 (2013).

3. Mohamed A. Ramadan*1, S.H.Nassar1, Abeer A. Abd El Aty2, Mahmoud I. Nassar3, Abdelsamed I. Elshamy3, Ahmed S. Montaser1, F. Kantouch1, "Antimicrobial Fabrics Using Conocarpus erectus Aqueous Extract", Egyptian Journal of Chemistry, (60)6, pp.1111-1121 (2017).

4. A. Farouk and S. Sharaf, " Sol-gel Hybrid Nanomaterials Based on TiO2/SiO2 as Multifunctional Finishing for Cotton Fabric", Egyptian Journal of Chemistry, (59)3, pp. 407-427 (2016).

5. Arafa, Abeer S., Suzan H. Sanad and Shereen O. Bahlol, "Nanotechnology Application on Cotton fibers, Yarn and Fabric and their Impact on Qualities and Antimicrobial Resistance", Egyptian Journal of Agricultural Research, (92) 1, pp. 153-167 (2014).

6. W. Akbar et al., "Characterization and Antibacterial Properties of Nano boron Powders and Nano boron Powder Coated Textiles", Journal of Advanced Powder Technology, (28), pp. 596-610 (2017).

7. Amr Fouda et al, "*In-Vitro* Cytotoxicity, Antibacterial, and UV Properties of the Biosynthesized Zinc Oxide Nanoparticles for Medical Textile Applications", Journal of Microbial Pathogenesis, (125)12, pp.252–261 (2018).

8. S. Nourbakhsh et. al., "Copper nanoparticles for Antibacterial Properties of Wrnkle Resistant Cotton Fabric", Material today Proceedings, (4). (2017).

9. Lingayya Hiremath, et. al.," Development of Antimicrobial Smart Textiles Fabricated with Magnetic Nanoparticles Obtained Through Green Synthesis", Journal of Materials Today, (5) 10, Part 1, pp. 21030-21039 (2018).

10. Karthik Ramaratnam Ph.D. et al. "Ultra hydrophobic Textiles Using Nanoparticles: Lotus Approach", Journal of Engineered Fibers and Fabrics, (3), pp. 1-14 (2008).

11. 11- Y. W. H. Wong et al, "Selected Applications of Nanotechnology in Textiles", AUTEX Research Journal, (6) 1, pp. 1-8 March (2006)

12. H. M. Fahmy, A. Amr, A. A. Aly, Sh. M. Sayed, "Synthesis of castor oil/2,4-toluene diisocyanate adduct to impart water repellency and antibacterial properties for cotton/polyester fabric", Journal of Coatings Technology and Research, , (16) 1, pp. 31-39 January (2019).

13. S Kathirvelu e.t al, "UV Protection Finishing of Textiles Using ZnO Nanoparticles", Indian Journal of Fiber and Textile Research, (34) 9, pp. 267-273 (2009).

14. J.K Patra and S. Gouda, "Applications of Nanotechnology in Textile Engineering: An overview", Journal of engineering and technology research, (5) 5, pp. 104-111 June (2013).

15. Eman Raafat and Nashwa Mostafa, "Effect of Coating with Silver Nanoparticles (AgNPs) on Cotton Fabric Functional Properties", International Design Journal, (4) 2, pp.33-39 (2014).

16. Elina Bosi et. al., "Environmental Sustainability Evaluation of Innovative Self Cleaning Textiles", Journal of Cleaner Production, (133), pp. 439-450 (2016).

17. Kristina Klinkhammer et. al., "Structured Textile Surfaces for Easy-to-Clean Properties towards

Dry Soil", Materials Today Proceedings, (4) pp. 101-106 (2017).

18. Subhranshu Sekhar Samal et. al., "Sonochemical Coating of Ag-TiO_2 Nanoparticles on Textile fabrics for stain Repellency and Self –Cleaning- The India Scenario: A Review", Journal of Minerals and Materials Characterization and Engineering, (9) 6, pp. 519-525 (2010).

19. Nabil A. Ibrahim*, Amal A. Aly, Basma M. Eid, and Hesham M. Fahmy, "Green Approach for Multifunctionalization of Cellulose-Containing Fabrics", Fibers and Polymers, (19) 11, pp. 2298-2306 (2018).

20. Elham Katoueizadeh et. al, "Synthesis and Enhanced Visible-Light Activity of N-doped TiO_2 Nano-Additives Applied over Cotton", Journal of Material Research and Technology, (7) 3, pp. 204-211 (2017).

21. Lipika Das and Jayanta Kumar Basu, "Photocatalytic Treatment of Textile Effluent using Titania-Zicronia Nano Composite Catalyst", Journal of Industrial and Engineering Chemistry, (24), pp. 245-250 (2015).

22. Jahanzeb Khan, Sadia Ilyas et. al, "ZnO/NiO Coated Multi-Walled Carbon Nanotubes for Textile Dyes Degradation", Arabian Journal of Chemistry, (11), pp. 880-896 (2018).

23. Tianyiyi He et. al., "Beyond Energy Harvesting- Multi-Functional Triboelectric Nano Sensors on a Textile", Journal of Nano Energy, (57), pp. 338-352 March (2019).

24. Shaohua Wu et. al., "Flexible and Conductive Nanofiber- structured Single Yarn sensor for Smart Wearable Devices", Journal of Sensors and Actuators B: Chemical, (252), pp. 697-705 November (2017).

25. Ahmed Almusallam et. al., "Flexible Piezoelectric Nano-Composite Films for Kinetic Energy Harvesting from Textiles", Journal of Nano Energy, (33), pp. 146-156 March (2017).

26. Kunal Singha et.al, "Recent advancements in Wearable & Smart Textiles: An Overview", Materials today Proceedings, (16), part 3, pp. 1518-1523 (2019).

27. Peng Sun et.al, "Stretchable Ni@NiCoP Textile for Wearable Energy Storage Clothes", Journal of Nano Energy, , (55), pp. (506-515) January (2019).

28. Chaoxing Wu et.al, "Wearable Ultra-Lightweight Solar Textiles based on Transparent Electronic Fabrics", Journal of Nano Energy, (32), pp. 367-373 February (2017).

29. Zhiqing Bai et.al, "Textile-based Triboelectric Nano-generators with High Performance via Optimized Functional Elastomer Composited Tribo-materials as Wearable Power Source", Journal of Nano Energy, on line-104012- (65). August (2019)

30. Mingchao Zhang et.al, "Printable Smart Pattern for Multi-Functional Energy- Management E-Textiles", Journal of Matter, X, (1), pp.168-179 July (2018).

31. Jie Chen et.al, "Traditional weaving craft for One-Piece Self-Charging Power Textile for Wearable Electronics", Journal of Nano Energy, (50), pp. 536-543 August (2018).