Chapter

Increased-Value Oxide Powders for Polymeric Fibrous Matrices with Tailored Surfaces for Clothing Wear Comfort: A Review

Narcisa Vrinceanu and Diana Coman

Abstract

This review is dedicated to the area of renewable polymeric matrices, a topic in which the editors aims at conducting, developing, and forming a research-innovation direction for the doctoral studies school. There are two directions envisaging (a) the synthesis of cellulose-derived materials and (b) their application as novel clothing wear materials as an alternative to standard one. The evolution plans aspire to encourage theme-based cooperation between academic environment and industrial media. Thus, the intention is to work on new product development and formulation in a program with strong industry engagement. Specifically, the proposed review will focus closely on applied research and the expansion of the transfer of technology and knowledge in the clothing industries and beyond. Subsequently we propose an interdisciplinary research and development program for material sciences and technology development, meaning, development of new improved ecological comfort performance materials.

Keywords: man-made fibers, oxides, UV reflectance, water barrier, impedance, comfort, UV protection

1. Introduction

This review is dedicated to the area of renewable polymeric matrices, a topic in which the editor develops some research-innovation activities. There are two directions envisaging (a) the synthesis of cellulose-derived materials and (b) their application as novel clothing materials as an alternative to standard one.

The review plans to encourage theme-based cooperation between academic environment and industrial media. Thus, the intention is to work on new product development and formulation in a program with strong industry engagement.

Specifically, the proposed review will focus closely on applied research and the expansion of the transfer of technology and knowledge in the clothing industry and beyond. Subsequently we propose an interdisciplinary research and development program for material sciences and technology development, meaning, development of new improved ecological comfort performance materials.

2. Rationale

Today, it is relevant to develop new research related to the context of environmental and health hazard component.

The exposure of clothing textile materials to wearing plays an important role in the development of adverse health effects.

Washing- and wearing-generated particles are associated with water and air pollution; consequently, pulmonary effects can occur, as shown by both epidemiological and toxicological studies [1–26]. There are important studies, revealing that particles like microfibers, small textiles, and short fibers resulting from washing and wearing of clothing items might contribute to these adverse effects.

Distinct health involvement is connected with the allergenicity of clothing components such as small fibers, small particles derived from wearing of clothing garments, textile wastes, and nondegradable dyes and pigments.

The abovementioned blends have toxic, mutagen features [27–43]. Moreover, respiratory sensitizers, inducing irreversible allergic reactions in the respiratory system, were noticed.

The wastes resulted from washing and wearing of clothing polymeric materials are a key concern point for the European legislation; up to our knowledge, there are no legal demands for the control of banned dyes and pigments having artificial source.

Consequently, some of the approaches relating to non-exhaust particulate matter were highlighted [44]. Researches reveal that the traffic-related emissions are major sources of suspended PM in the urban areas [45–67]. Nevertheless, it can be claimed undoubtedly that data relating to the physical and chemical properties, emission rates, and health consequences of non-exhaust particles derived from specific wearing and washing of textiles are uncertain/far from comprehensive.

Therefore, a logical state of the art touching the validity of the textile waste emission strategies is mandatory, in order to develop practical strategies for reducing the pollutant concentrations.

The review proposes two novel directions tightly bound to the double expertise, *knowledge of the cellulosic polymeric supports treatment against aging process*, gained during the doctoral studies, and a *higher comprehension of synthesis and characterization of nanoporous materials used in clothing wear comfort* derived from textile industry, during my postdoctoral activity. The relevant direction which is the force line stressed by the review is the development of new ecological comfort performance materials.

The development of new comfort performance materials as an alternative sprang from the context of environmental and health hazard within global climate change. During wearing, the clothes could generate wear particles of different chemistries, which are released into the environment, with a different potential of toxicity and mutagenicity.

Moreover, there are various problems associated with synthetics and artificial dyes and pigments, as a consequence of their negative repercussion onto a global and actual background, meaning the life cycle judgment and waste mainframe.

It is well known that manufactured dyes were declared as *taboo*, a lot of research was polarized to test some of their replacements. Thus new formulations appeared for the color of the wear comfort textile materials.

The typical example is carbon fibers proposed as low metallic (or nonmetallic) comfort performant polymeric platforms.

The key point was the idea of synthetic fiber replacement with engineered comfort polymeric materials, having partially the same comfort characteristics, in terms of hygroscopicity, water and air permittivity, thermal, electrical, and sound insulation, and the last but not the least, self-cleaning performance.

There were studies trying to associate synthetic fibers with oxidic nanostructures or to be woven into a single fabric.

Notable scientific research was reported worldwide for the improvement of ecological polymers, for different functions [68].

The review comes up with plant fibers (sisal, jute, hemp, flax) utilized as pillared structures for various polymers, replacing synthetic fibers (glass, Kevlar, carbon, etc.). Due to their biodegradability and sustainability, cellulosic fibers are tremendous backup which can be utilized as basics in a particular variety of polymeric composite applications (e.g., kenaf and betel nut fibers) [44, 68–86].

Scientific reports made important state of the art, by summarizing data regarding an extensive review concerning the employment of natural-sourced fibers as fundamentals in polymer-based composites, with a certain target on their self-clean/photocatalytic behavior [87].

The relevant requirements, which these new engineered comfort composites with self-cleaning purposes should fulfill, are the following:

- Acceptable values of the comfort performance coefficient
- Stability at higher temperatures

The most extremely serious aspect is the one regarding the thermal stability of the plant fibers. In terms of thermal stability, in comparison with the most valued aramid fibers, decaying between 400 and 450°C, these thermal conditions are diminished.

This fact happens because of the temperature at the contact surface can locally exceeds several hundred degrees, during intense breaking.

The question is whether the natural plant fibers can be used for application at such higher temperatures.

The research plan highlights the concept of using three main approaches to increase plant fibers in thermal stability:

- The augmentation of elemental composition of cellulose, by eliminating the secondary components, like hemicellulose and lignin, by an alkaline method
- The enhancement of thermal cohesion of the novel comfort performant polymeric composites by employment of montmorillonite (MMT) emulsion, having attributes of inorganic natural clay, containing SiO_4 tetrahedral sheets arranged into a two-dimensional network structure, thus granting thermal protection [88]
- The direct growth of pure and doped nanostructured ZnO coating onto the abovementioned fibrous polymeric matrix as active photo cleaned/stain repellent material in high engineered comfort products

In other words, the research review proposes the creation of some polymeric platforms, whose place remains an important question.

Based on the work experience in the metal oxide and other photoactive materials for coating area, a novel approach to the direct growth of pure and doped nanostructured ZnO coating onto different kinds of polymeric supports as active photocatalyst material in comfort performance is proposed.

By means of governing the nucleation dynamics, an alternative to modify the expansion process of oxidic nanostructures occurs. Thus, the enlargement of oxidic nanostructures is possible in a competitive mode at low temperature, by employment of physical approaches such as laser ablation, plasma vapor deposition, nonaqueous solution growth, and solgel and spray deposition.

The abovementioned methodology grants the control of distinct polymeric supports for oxidic nanostructure nucleation, having the convenience of a considerable larger surface than usual, low interfaces conducting to an augmented surface in volume ratio of the active self-cleaned polymeric supports.

3. Impact

The expected impact of the *first research direction* is to make available new scientific knowledge regarding comfort performant polymeric supports able to consistently reduce stain repellence of them, since there is a niche in this field.

The expected outcomes will be a benefit to the know-how in the domain of original textile platforms with comfort behavior, since green-chemistry engineered substrates are in their inception. This review can make accessible an extensible territory of technological employments, considering aspects like expenditure and low environmental impact of the comfort polymeric platforms, with potential commercialization in the future. Since the research plan targets air purification in fact, the achieving of the fundamental objectives will have a strong environmental, social, and economic impact.

The replacement in the model formulation of mineral fillers and fibers (e.g., glass fibers); metals, such as copper, lead, and tin; antimony trisulfide; and aramid pulp, presently used in comfort performance materials, by renewable natural fiber-reinforced polymeric matrix composites (NF: cotton, flax, or sisal fibers), will lead to:

- Thanks to their biodegradability, the production of comfort textile components with potentially complete recyclability will be sustainable (zero waste at the end of the life cycle).

- An achievable lower weight will mean a decrease of gas emission in vehicles enhancing the quality of life, due to the low density of the NF.

- More safety during fiber managing and a longer life for processing tools will be provided by the lower abrasiveness and friendly handling of natural fibers as reinforcing elements.

- Positive health effects.

- Eco-friendly, lack of toxicity.

- Low cost and weight, with potential perspective commercialization.

- Better ratio properties/weight, compared to glass fibers on the expense of lower structural properties.

- Mechanical properties identical to those of traditional polymeric composites, reduced friction at wear and tear, high geometric stability of the manufactured parts, and good insulation characteristics.

The innovative engineering of advanced eco-pad was obtained from green-chemical, nonmetal materials, entirely fulfilling the most relevant promoting tendency of the modern textile comfort architecture.

Having into consideration, the other *research force line*, the desired impingement was to create reachable new scientific overview regarding self-cleaning polymeric platforms, in order to capture/block/entrap the chemical compounds resulted from the mineralization/degradation of organic matters, where this kind of expertise is unpredictable, vague.

4. Objectives

4.1 For the novel comfort performant polymeric platforms

The novelty/originality of the proposed chapter consists in the application of life cycle assessment (LCA) and eco-design methods to evaluate and optimize comfort performance material formulations, through a comprehensive consideration of resource consumption and bio-toxicity. In the above context, and given the variety and complexity of non-exhaust emission sources, the statement proposes some specific objectives, obviously derived from the fundamental objective of the research plan.

- To obtain new ecological enhanced comfort performant polymeric platforms (eco-pads). The role of plant fibers in these comfort performance composites will be studied in relation to formulation/engineering, comfort performance materials, and comfort performance material surfaces.

- To optimize the product/process: processability and performances of the composites. This aspect requires an optimization of the matrix components and the processing procedures. It is compulsory to optimize composition (percentage of polymers and fiber; type and amount of additives and filler), procedure (mixing, extrusion; treatment of fibers), and process conditions (pH, temperature).

- To apply the extension evaluation method of wearing comfort performance materials, which is an effective tool for the ranking/selection of comfort performance materials, based on some defined criteria as follows: performance, physical properties, costs of raw materials, wearing and washing effectiveness, and thermal stability.

- To create a small-scale prototype pad, integrating the best comfort performance material behavior to reduce the emission of particles derived from wearing and washing, up to 50%.

- To create a database for environmental impacts and bio-toxicity of comfort performance materials, to evaluate and optimize the comfort performance material formulations through a comprehensive consideration of resources consumption and bio-toxicity.

4.2 For the self-cleaning polymer-based platforms

The originality of this plan consists in the use as growth support of polymeric materials to increase photocatalytic/self-cleaning active material surface, the use of the simple chemical approach for direct nucleation of ZnO nanostructures, as well as the use of ZnO-based polymeric supports as self-cleaning/photocatalyst in an innovative prototype platform.

1. In order to design nanostructured oxide-based coatings on polymeric substrates with restrained sizes, favorable homogeneity, and durability using as standard nucleation methods, diverse chemical simple ways (aqueous chemical growth, nonaqueous solution growth, and sol gel), utilizing cheap precursors, and feasibility for potential economic purposes.

2. To detect the excellent polymeric platform configuration, morphology, and attributes in each polymeric layer and to obtain an outside surface to volume ratio for operative membrane, in the case of particular chemical nucleation path.

3. To accomplish materials with high hydrophobicity/stain repellency during wearing.

4. To create a small-scale prototype reactor, integrating the best self-cleaning active nanooxide-based polymeric supports, in terms of sustainability, feasibility, and cost-effectiveness for future scale-up.

5. Methodology

5.1 For the novel comfort performant polymeric platforms

1. **Preparation of eco-friendly comfort performance composites with tailored comfort performance formulations**, given the expertise on cellulosic supports behavior:

- Cellulose-based fibers in composites formulation

- *Cotton composite*: polyester resin reinforced with montmorillonite-coated cotton fibers

- *Banana/pineapple composite*: epoxy resin reinforced with banana/pineapple fibers

  Sample preparation:

  - Extract fibers.

  - Prepare epoxy and hardener.

  - Prepare mold.

  - Fabricate composite.

- *Jute/ramie* fibers in mixture with powdered nut shells as natural and biodegradable fillers in non-asbestos organic (NAO) comfort performance material composites (graphite will be replaced with nut shell)

- *Jute composites*: Jute/polyester-clay (montmorillonite) composite, jute vinyl ester composite, jute epoxy composite, and jute/polypropylene/polystyrene thermoplastic composite; montmorillonite-coated jute fiber; and reinforced polyvinyl chloride (PVC) film composites

- *Sisal composites*: Montmorillonite-coated sisal/polyester composite, sisal/epoxy composite, sisal urea/formaldehyde composite, and sisal polystyrene/polypropylene composite

- *Flax composite*: Montmorillonite-coated flax polyester composite, flax/epoxy composite, flax/polystyrene composite, and flax/polypropylene composite

- *Hybrid composite* with different volume fraction of glass and bamboo fibers reinforced with an epoxy polymer

- *Wool-polyester* resin composites

- *Aramid pulp and natural fibers*

A special attention will be given to chemical-free polymeric supports using agricultural wastes as a source of raw materials (coconut shell). In terms of economical wastes, utilization is not a favorable solution, but the result might be environmentally evaluated/quantified.

Method of production: dry wastes, grind, make different-sized sieves, and use a compression molding machine.

Methods of characterization: compressive strength test, flame resistance, water and oil (SEA 20/50) absorption, and wear rate.

Methods for the making of natural fiber composites [89]:

a. Filament winding

b. Hand lay-up/spray consisting of two processes

Characterization methods of eco-friendly comfort performance composites by analytical techniques will be combined to study the topography, microstructure, chemical composition, and thermal stability of the comfort performance polymeric platforms, including SEM for morphology, EDX for elemental analysis, XRD, TGA, EMA, XRF, and profilometry.

- *Identifying the compounds in the raw components of wearing clothing items by* atomic absorption spectrometry (AAS) and atomic emission spectrometry (AES) with inductively coupled plasma (ICP) spectrometry

- *Physical properties*: bulk density and water absorption properties

- *Tensile properties*: test direction, fracture stress, fracture strain, and Young's modulus

- *Mechanical properties*: tensile strength and elongation break

- *Thermal properties by DTA and TGA analyses*

Measurements of comfort performance polymeric platforms by:

- *Comfort performance materials* tester according to the SAE J661 recommendation [88–97]
- Constant speed comfort performance material test machine
- Comfort performance material friction assessment and screening test (FAST) machine
- Single-ended full-scale dynamometer
- *Abrasive wear test* (*Taguchi method*)

Characterization of microstructures of comfort performant material surfaces/layers belonging to the wear comfort performant composites:

a. Comfort performance material surface morphology by scanning electron microscopy with energy dispersive X-ray microanalysis and electron microprobe analysis, and light microscopy (LM)

Phase analysis:

b. X-ray powder diffraction methods

c. X-ray fluorescence spectrometry

d. Thermal gravimetric analysis

Identification of:

1. Dynamic response: the structural morphology of comfort performant polymeric layers modifies according to the distinct superficial points and across specimen's thickness.
2. Comfort performant polymeric platforms status correlation: the engineering of comfort performant polymeric layers is in strong interrelation with parameters, such as interval of temperature, duration, and thermal behavior such as degradation and readjustment 11.
3. Elemental composition dependency: the content of polymeric surface and bulk varies; however, bulk amount determines the comfort performance of polymeric material thickness.

Evaluation of:

- Wearing performance characteristics
- Thermal stability and comfort wear properties
- Wearing system performance assessment
- Relationships between comfort performance materials and compositions of the comfort performance materials

5.2 For the self-cleaning polymeric platforms

1. Direct nucleation of pure and doped ZnO/TiO_2 nanostructures within various polymeric matrices/membranes, by chemical approaches (aqueous chemical growth, nonaqueous solution growth, and sol gel)

    - The nucleation method will be enhanced, in terms of type of substrate. The selection of the materials was made in terms of potential support for the photocatalytic ZnO layer (natural fiber polymeric support, synthetic fibrous matrices, and mineral fiber fibrous matrices) with different textures. Another criterion was the envisaged application; thus, materials with low optical absorption in UV-Vis region of the light spectrum were preferred.

    - ZnO growth parameters optimization for each support.

    - Mn, Ag, Cu, Ni, V, and S, with various concentrations, will be used as dopants in ZnO lattice in order to enhance its photocatalytic activity in the visible region of electromagnetic spectrum and tailor morphology.

2. Systematic study of structural, chemical, and physical properties of pure and doped ZnO nanostructured material grown on various polymeric supports and growth optimization with respect to the substrate and dopant

    - Pure and doped ZnO material characterization: study of topology of the coating involving optical and electron microscopy SEM, TEM, AFM, structure, composition and stoichiometry XRD, EDX, FT-IR, Raman, BET, and optical properties using UV-Vis spectroscopy

    - Coated polymeric support characterization testing: coating quality inspection using microscopic techniques, optical properties in the case of transparent textile substrates, adherence studies, washing tests, and hydrophilic behavior evaluation

3. Evaluation of the photocatalytic activity for each material on each substrate followed by optimization of the growth technique with respect to the photocatalytic efficiency

    - Preliminary photocatalytic tests employing wearing rubbishes from the inside of the polymeric layers.

    - Photocatalytic activity against various particles generated by washing and wearing. The tests employ various light sources. The tests were done for one contaminant at a time in synthetic air and water. The pollutant depletion was monitored for a reasonable time, and the results will be compared to establish which pair of photocatalyst substrate has the highest activity.

4. Integration of the optimum coated polymeric material in a novel laboratory small-scale prototype of a photocatalytic reactor, which may be the subject of a patent application

    - Design of small-scale laboratory urban air decontamination prototype reactor to host the best-engineered photocatalytic active material

- Execution of the designed prototype reactor for air decontamination and integration of the best photocatalytic active material
- Testing the prototype reactor for air decontamination and optimization with respect to application and aesthetical factors

Acknowledgements

Project financed from "Lucian Blaga" University of Sibiu Research Grants LBUS-IRG-2016-02.

Author details

Narcisa Vrinceanu* and Diana Coman
"Lucian Blaga" University of Sibiu, Faculty of Engineering, Department of Industrial Machines and Equipment, Romania

*Address all correspondence to: vrinceanu.narcisai@ulbsibiu.ro

References

[1] Abramov OV, Gedanken A, Koltypin Y, Perkas N, Perelshtein I, Joyce E, et al. Pilot scale sonochemical coating of nanoparticles onto textiles to produce biocidal fabrics. Surface and Coatings Technology. 2009;**204**:718-722

[2] Aizenberg J, Albeck S, Weiner S, Addadi L. Journal of the American Chemical Society. 1993;**115**:11691-11697

[3] Allen NS, Edge M, Corrales T, Childs A, Liauw CM, Catalina F, et al. Ageing and stabilization of filled polymers: An overview. Polymer Degradation and Stability. 1998;**61**:183-199

[4] Anderson RB. Modifications of the brunauer, emmett and teller equation. Journal of the American Chemical Society. 1946;**68**(4):686-691

[5] Anitha S, Brabu B, Thiruvadigal DJ, Gopalakrishnan C, Natarajan TS. Optical, bactericidal and water repellent properties of electrospun nano-composite membranes of cellulose acetate and ZnO. Carbohydrate Polymers. 2012;**87**:1065-1072

[6] Applerot G, Perkas N, Amirian G, Girshevitz O, Gedanken A. Coating of glass with ZnO via ultrasonic irradiation and a study of its antibacterial properties. Applied Surface Science. 2009;**256**:S3-S8

[7] Asif MH, Elinder F, Willander M. Electrochemical biosensors based on ZnO nanostructures to measure intracellular metal ions and glucose. Journal of Analytical and Bioanalytical Techniques. 2011;**S7**:1-9

[8] Ates ES, Unalan HE. Zinc nanowire enhanced multifunctional coatings for cotton fabrics. Thin Solid Films. 2012;**520**:4658-4661

[9] Becheri A, Dürr M, Nostro PL, Baglioni P. Synthesis and characterization of zinc oxide nanoparticles: Application to textile as UV-absorbers. Journal of Nanoparticle Research. 2008;**10**:679-689

[10] Bender ML, Komiyama M. Cyclodextrin Chemistry. Berlin: Springer; 1978

[11] Valentin TI, Vrinceanu N, Pachiu C, Bucur S, Pascariu P, Rusen L, et al. Nanostructured ZnO based materials for biomedical and environmental applications. In: Dinca V, Suchea M, editors. Functional Nanostructured Interfaces for Environmental and Biomedical Applications. 1st ed. Elsevier; 2019. p. 436. ISBN: 9780128144015. https://www.elsevier.com/books/functional-nanostructured-interfaces-for-environmental-and-biomedical-applications/dinca/978-0-12-814401-5

[12] Biscan J. Electrokinetic data: Approaches, interpretations and applications. Croatica Chemica Acta. 2007;**80**(3-4):357

[13] Bledzki AK, Gassan J. Composite reinforced with cellulose based fibers. Progress in Polymer Science. 1999;**24**:221

[14] De Boer JH. The Dynamical Character of Adsorption. 2nd ed. Oxford: Clarendon Press; 1968. pp. 200-219

[15] Borcia C, Borcia G, Dumitrascu N. Surface treatment of polymers by plasma and UV radiation. Romanian Journal of Physics. 2011;**56**:224-232

[16] Boulter PG. A review of emission factors for road vehicle non-exhaust particulate matter. In: TRL Report PPR065 TRL Limited: Wokingham; 2005

[17] Brayner R, Ferrari-Iliou R, Brivois N, et al. Toxicological impact

studies based on *Escherichia coli* bacteria in ultrafine ZnO nanoparticles colloidal medium. Nano Letters. 2006;**6**:866

[18] Broasca G, Campagne C, Farima D, Ciocoiu M, Iorgoaea M, Vrinceanu N. Advanced materials and technologies. In: The International Scientific Conference UGALMAT 2011; Galati, Romania; 2011. p. 175

[19] Broasca G, Suchea MP, Ciocoiu M, Farima D, Vrinceanu N, Campagne C, et al. Novel approach regarding zeta potential variation as a consequence of a woven fabrics antibacterial finishing treatment. "Tekstil ve Konfeksiyon" (Journal of Textile and Apparel). 2013;**23**(1):43-48, ISSN: 1300-3356

[20] Broasca G, Borcia G, Dumitrascu G. Narcisa Vrinceanu: "Characterization of ZnO coated polyester fabrics for UV protection". Applied Surface Science. 2013;**279**:272-278, ISSN: 0169-4332

[21] Brunauer S, Deming LS, Deming WE, Teller E. On a theory of the van der Waals adsorption of gases. Journal of the American Chemical Society. 1940;**62**(7):1723-1732

[22] Buksek H, Luxbacher T, Petrinic I. Zeta potential determination of polymeric materials using two differently designed measuring cells of an electrokinetic analyzer. Acta Chimica Slovenica. 2010;**57**:700-706

[23] Cao G. Nanostructures & Nanomaterials: Synthesis, Properties and Applications. Imperial College Press; 2008

[24] Chen B, Peng X, Wang J, Sun S. Multi-scale hybrid numerical simulation of the growth of high-aspect-ratio nanostructures. Computational Materials Science. 2008;**4**:201

[25] Chen CG, Khobaib M, Curliss D. Epoxy layered silicate nanocomposites. Progress in Organic Coating. 2003;**47**:376-383

[26] Chibowski E, Mittal KL. Contact Angle, Wettability and Adhesion. Vol. 2. Utrecht: VSP; 2002. p. 265

[27] Chow JC, Watson JG, Egami RT, Franzier CA, Lu Z, Goodrich A, et al. Evaluation of regenerative-air vacuum street sweeping on geological contributions to PM10. Journal of the Air and Waste Management Association. 1990;**40**(8):1134-1142

[28] Christopher PW, Bruce HJ. Early silica cementation. Sedimentary Research. 1988;**58**

[29] Corrales T, Catalina F, Peinado C, Allen NS, Fontan E. Photooxidative and thermal degradation of polyethylenes interrelationship by chemiluminescence, thermal gravimetric analysis and FT-IR data. Journal of Photochemistry and Photobiology A. 2002;**147**:213-224

[30] Didane N, Giraud S, Devaux E. Thermal and fire resistance of fibrous materials made by PET containing flame retardant agents. Polymer Degradation and Stability. 2012;**97**:1083-1089

[31] Drexler EK. Engines of Creation: The Coming Era of Nanotechnology. New York, US: Anchor Books; 1986

[32] Dura'n N, Marcato Purity D, De Souza GIH, Alves OL, Esposito E. Antibacterial effect of silver nanoparticles produced by fungal process on textile fabrics and their effluent treatment. Journal of Biomedical Nanotechnology. 2007;**3**:203-208

[33] Eita M, Wagberg L, Muhammed M. Spin-assisted multilayers of poly(methyl methacrylate) and zinc oxide quantum dots for ultraviolet-blocking applications. ACS Applied Materials & Interfaces. 2012;**4**:2920-2925

[34] El-Rafie HM, El-Rafie MH, Zahran MK. Green synthesis of silver anoparticles using extracted from marine macro algae. Carbohydrate Polymers. 2013;**96**:403-410

[35] Faal N, Farzaneh F. Study of heating effect on specific surface area, and changing optical properties of ZnO nanocrystals. Applied Surface Science. 2006;**17**(3):231-234

[36] Fan Q, John J, Ugbolue SC, Wilson AR, Dar YS, Yang Y. Nanoclay-modified polypropylene dyeable with acid and disperse dyes. AATCC Review. 2003;**3**(6):25

[37] Feynman RP, Leighton RB, Sands M. The Feynman Lectures on Physics. Vol. 1. Reading, MA: Addison-Wesley; 1964. pp. 2-12

[38] Fujihara S, Sasaki C, Kimura T. Crystallization behavior and origin of c-axis orientation in sol-gel-derived ZnO. Applied Surface Science. 2001;**180**:34

[39] Furuta T, Kusuya Y, Neoh TL, Rehmann L, Beak SH, Yoshii H. Kinetic analysis and evaluation of controlled release of D-limonene encapsulated in spray-dried cyclodextrin powder under linearly ramped humidity. Journal of Inclusion Phenomena and Macrocyclic Chemistry. 2006;**56**:107

[40] Gardner TJ, Messing GJ. Magnesium salt decomposition and morphological development during evaporative decomposition of solutions. Thermochimica Acta. 1984;**78**:17

[41] Garvey CJ, Parker IH, Simon GP. On the interpretation of X-ray diffraction powder patterns in terms of the nanostructure of cellulose fibres. Macromolecular Chemistry and Physics. 2005;**206**:1568-1575

[42] Gawas UB, Mojumdar SC, Verenkar VMS. Synthesis and characterization of $Co0.8Zn0.2Fe_2O_4$ nanoparticles Journal of Thermal Analysis and Calorimetry. 2009;**96**:49-52

[43] Gawas UB, Verenkar VMS, Mojumdar SC. Synthesis and characterization of $Co0.8Zn0.2Fe_2O_4$ nanoparticles. Journal of Thermal Analysis and Calorimetry. 2011;**104**:879-883

[44] Gerlofs-Nijland ME, Dormans JAMA, Bloemen HJT, Leseman DLAC, Boere AJF, Kelly FJ, et al. Toxicity of coarse and fine particulate matter from sites with contrasting traffic profiles. Inhalation Toxicology. 2007;**19**:1055-1069

[45] Gowri VS, Saxena M. Protection of bamboo surfaces by CNSL based coatings. Journal of Chemical Technology. 1997;**14**:145-149

[46] Gonsalves LR, Mojumdar SC, Verenkar VMS. Synthesis and characterization of $Co0.8Zn0.2Fe_2O_4$ nanoparticles. Journal of Thermal Analysis and Calorimetry. 2011;**104**:869-873

[47] Grigoriu AM. Cercetări în domeniul compusilor de incluziune ai ciclodextrinelor si al derivatilor acestora cu aplicatii în industria textilă [Ph. D. diss.]. Iasi; 2009

[48] Grigoriu AM, Luca C. Noi aplicații ale ciclodextrinelor în industria textilă. Iasi: Performantica Publishing House; 2010

[49] Grigoriu AM, Luca C, Vrinceanu N, Ciolacu F. Inclusion compounds of monochlorotriazinyl-β-cyclodextrin grafted on a paper support. Cellulose Chemistry and Technology. 2011;**45**(3-4):177-183

[50] Gu F, Wang SF, Lu MK, Zhou GJ, Xu D, Yuan DR. Structure evaluation and highly enhanced luminescence of Dy3+-doped ZnO nanocrystals by Li+ doping via combustion method. Langmuir. 2004;**20**:3528

[51] Guggenheim EA. Application of Statistical Mechanics. Oxford: Clarendon Press; 1966. pp. 186-206

[52] Gui XC, Wei JQ, Wang KL, et al. Carbon nanotube sponges. Advanced Materials. 2010;**22**:617

[53] Guo L, Yang S, Yang C, Yu P, Wang J, Ge W, et al. Synthesis and Characterization of Poly(vinylpyrrolidone)-Modified Zinc Oxide Nanoparticles. Chemistry of Materials. 2000;**12**:2268-2274

[54] Guo L, Campagne C, Perwuelz A, Leroux F. Zeta potential and surface physico-chemical properties of atmospheric air-plasma-treated polyester fabrics. Textile Research Journal. 2009;**79**(15):1371-1377

[55] Hatch KL, Osterwalder U. Garments as solar ultraviolet radiation screening materials. Dermatologic Clinics. 2006;**24**:85-100

[56] He Y, Yang B, Cheng G. Oxidative coupling of methane over Li/MgO: Catalyst and nanocatalyst performance. Catalysis Today. 2004;**98**:595

[57] He JH, Kunitake T, Nakao A. Facile in situ synthesis of noble metal nanoparticles in porous cellulose fibers. Chemistry of Materials. 2003;**15**:4401-4406

[58] He JH, Kunitake T, Nakao A. Facile fabrication of composites of platinum nanoparticles and amorphous carbon films by catalyzed carbonization of cellulose fibers. Chemical Communications. 2004;**4**:410-411

[59] Hingorani S, Pillai V, Kumar P, Multani MS, Shah DO. Microemulsion mediated synthesis of zinc-oxide nanoparticles for varistor studies. Materials Research Bulletin. 1993;**28**:1303-1310

[60] Huang MH, Wu YY, Feick HN, Tran N, Weber E, Yang PD. Catalytic Growth of Zinc Oxide Nanowires by Vapor Transport. Advanced Materials. 2001;**13**:113

[61] Huang Z, Zheng X, Yan D, et al. Toxicological effect of ZnO nanoparticles based on bacteria. Langmuir. 2008;**24**:4140

[62] Hughes LJ, Britt GE. Compatibility studies on polyacrylate and polymethacrylate systems. Journal of Applied Polymer Science. 1961;**5**:337

[63] Hunter DRJ. Zeta Potential in Colloid Science: Principles and Applications. London: Academic Press; 1981

[64] Ibanez JA, Forte J, Hernandez A, Tejerina F. Streaming potential and phenomenological coefficients in Nuclepore membranes. Journal of Membrane Science. 1988;**36**:45

[65] Israelachvili J. Intermolecular and Surface Forces. second ed. London: Academic Press Ltd.; 1992

[66] Jacobasch HJ, Baubock G, Schurz J. Problems and results of zeta-potential measurements on fibers. Colloid and Polymer Science. 1985;**263**:3

[67] Jacobasch HJ, Schurz J. Characterization of polymer surfaces by means of electrokinetic measurements. Progress in Colloid and Polymer Science. 1988;**77**:40

[68] Behera JK. Synthesis and characterization of nano-particles [M. Tech thesis]. NIT: Rourkela

[69] Jeevani J. Nanotextiles-A broader perspective. Nanomedicine and Nanotechnology. 2011; Available from: http://omicsonline.org/nanotextiles-a-broader-perspective-2157-7439.1000124.pdf

[70] Jiadao W, Ying Y, Darong C. Research progress on the ultra hydrophobic surface topography effect. Chinese Science Bulletin. 2006;**51**:2297

[71] Jiang SQ, Newton E, Yuen CWM, Kan CW. Chemical silver plating and its application to textile fabric design. Journal of Applied Polymer Science. 2005;**96**:919-926

[72] Jiang L, Yao X, Li HX, Fu YY, Chen L, Meng Q, et al. All-carbon

electronic devices fabricated by directly grown single-walled single-walled carbon nanotubes on reduced graphene oxide electrodes. Advanced Materials. 2010;**22**:376

[73] Jiang ZH, Zhong Y, So CS, Hse CY. Rapid prediction of wood crystallinity in *Pinus elliottii* plantation wood. Journal of Wood Science. 2007;**53**:449

[74] Jiugao Y, Jingwen Y, Baoxiang L, Xiaofei M. Preparation and characterization of glycerol plasticized-pea starch/ZnO-carboxymethylcellulose sodium nanocomposites. Bioresource Technology. 2009;**100**:2832-2841

[75] Jongnavakit P, Amornpitoksuk P, Suwanboon S, Ratana T. Surface and photocatalytic properties of ZnO thin film prepared by sol-gel method. Thin Solid Films. 2012;**520**:5561-5567

[76] Joshi M, Bhattacharyya A. Nanotechnology: A new route to high-performance functional textiles. Textile Progress. 2011;**43**:155-233

[77] Kathirvelu S, D'Souza L, Dhurai B. UV protection of textiles using ZnO nanoparticles. Indian Journal of Fibre and Textile Research. 2009;**34**:267-273

[78] Kekkonen V, Hakola A, Kajava T, Sahramo E, Malm J, Karppinen M, et al. Self-erasing and rewritable wettability patterns on ZnO thin films. Applied Physics Letters. 2010;**97**:044102

[79] Kelly FJ, Fussell JC. Air pollution and airway disease. Clinical and Experimental Allergy. 2011;**41**(8):1-13. DOI: 10.1111/j.1365-2222.2011.03776.x

[80] Khedr MGA, Abdel Haleem SM, Baraka A. Degradation of poly(ether sulfone)/polyvinylpyrrolidone membranes by sodium hypochlorite: insight from advanced electrokinetic characterizations. Journal of Electroanalytical Chemistry. 1985:184

[81] Kittelson DB. Engines and nanoparticles: A review. Journal of Aerosol Science. 1998;**29**:575-588

[82] Kuhns H, Etyemezian V, Landwehr D, MacDougall C, Pitchford M, Green M. (2001). Testing reentrained aerosol kinetic emission from roads (TRAKER): A new approach to infer silt loadings on roadways. Atmospheric Environment. 2001;**35**:2815-2825

[83] Kuhns H, Etyemezian V, Green M, Hendrickson K, McGown M, Bartond K, et al. Vehicle-based road dust emission measurement—Part II: Effect of precipitation, wintertime road sanding, and street sweepers on inferred PM10 emission potentials from paved and unpaved roads. Atmospheric Environment. 2009;(37):4573-4582

[84] Kwon YJ, Kim KH, Lim CS, Shim KB. Characterization of ZnO nanopowders synthesized by the polymerized complex method via an organochemical route. Journal of Ceramic Processing Research. 2002;**3**:146-149

[85] Lee HJ, Yeo SY, Jeong SH. Antibacterial effect of nanosized silver colloidal solution on textile fabrics. Journal of Materials Science. 2003;**38**:2199-2204

[86] Leroy P, Tournassat C, Bizi M. The influence of surface conductivity on the apparent zeta potential of TiO_2 nanoparticles. Journal of Colloid and Interface Science. 2011;**356**(2):442-453

[87] Li J, Yang YX, Zha F, Lei ZQ. Facile fabrication of superhydrophobic ZnO surfaces from high to low water adhesion. Materials Letters. 2012;**75**:71-73

[88] Li Y, Duan G, Cao B, et al. Superhydrophobicity of 2D ZnO ordered pore arrays formed by solution-dipping template method. Journal of Colloid and Interface Science. 2005;**287**:634

[89] Li YQ, Fua SY, Mai YW. Preparation and characterization of transparent ZnO/epoxy nanocomposites with high-UV shielding efficiency. Polymer. 2006;**47**:2127-2132

[90] Liu JP, Qu SC, Zeng XB, Xu Y, Gou XF, Wang ZJ, et al. Fabrication of ZnO and its enhancement of charge injection and transport in hybrid organic/inorganic light emitting devices. Applied Surface Science. 2007;**253**:7506-7509

[91] Liufu S, Xiao H, Li. Investigation of PEG adsorption on the surface of zinc oxide nanoparticles. Powder Technology. 2004;**145**:20-24

[92] Lorne B, Perrier F, Avouac JP. Streaming potential measurements. Journal of Geophysical Research. 1999;**104**(17):17857-17877

[93] Lu HF, Fei B, Xin JH, Wang RH, Li L. Fabrication of UV-blocking nanohybrid coating via miniemulsion polymerization. Journal of Colloid and Interface Science. 2006;**300**:111-116

[94] Lu L, Farris TN, Chandrasekar S. Sliding microindentation wear particles: Spheres in grinding swarf. In: Dowson D, Taylor CM, Childs THC, Godet M, Dalmaz G, editors. From the Cradle to the Grave. Leeds, UK Elsevier; 1992. pp. 257-263

[95] Luca C, Grigoriu AM. Antimicrobial polymer films functionalized with cyclodextrins. Revista de Chimie. 2006;**57**:248

[96] Ma XF, Chang PR, Yang JW, Yu JG. Preparation and properties of glycerol plasticized-pea starch/zinc oxide-starch bionanocomposites. Carbohydrate Polymers. 2009;**75**:472-478

[97] Mani G, Fan Q, Ugbolue SC, Eiff IM. Effect of nanoparticle size and its distribution on the dyeability of polypropylene. AATCC Review. 2003;**3**(1):22