Safe Nanotextiles from a Life Cycle Perspective

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ABSTRACT

Enterprises aim to take advantage of the opportunities of new nanomaterials while producing safe products. A dose-effect relationship of the engineered nanoparticles has not yet been clearly established. From this viewpoint, a product will only be safe as long there is neither unintended release of engineered nanoparticles nor exposure to them during the product life cycle. In our study on textile applications, we found different integration modes as to how engineered nanoparticles could be integrated in textiles and be linked to the textile matrix. We analysed the factors that might influence the unintended release of engineered nanoparticles from textiles at some time in their life cycles. We conclude that release and exposure scenarios during the nanotextile life cycle depend on the design of the specific nanotextile. With our proposal we intend to provide a base for structuring further discussion on safe innovation for nanotextiles.

Keywords: ***nanoparticle release, life cycle, nanotextile, integration models, sustainable innovation***

1 INTRODUCTION

In the textile sector, nanotechnologies are expected to hold considerable potential for the development of new materials. Apart from improving their functionality, the use of nanotechnologies could lead to the production of textiles with completely novel properties or the combination of various functions in one fabric. These "multifunctional" textiles could open the way for the use of textile products in application fields outside the traditional industries such as, for example, in the construction, medical, transport, environmental or information sectors. Currently, numerous functions are under investigation such as antibacterial, conductive, anti-static, reinforced, self-cleaning, water-repellent, UV-blocking, flame-retardant textiles and dye ability, colour fastness and many more (e.g. [1 - 3]. In future nanotextiles could be ubiquitous in daily life and thus their safety is relevant.

From the viewpoint of environment health and safety (EHS), nanotechnologies probably entail both opportunities and risks. On the one hand, nanomaterials could be an alternative to hazardous chemical additives (e.g. flame retardants) or could contribute to keeping the consumption of material resources more economical. On the other hand, various organisations have expressed their concern about potential effects on human health and the environment through the exposure to engineered nanoparticles and the lack of regulatory measures (see e.g. [4]).

Currently, there are major knowledge gaps in regard to the health and environmental risks posed by engineered nanoparticles [5-8]. Some of the uncertainties are fundamental and probably will remain for the coming years. From this viewpoint, the textile products are only safe as long there is no unintended release of engineered nanoparticles during their life cycles. Up to now it has been assumed that solid materials with embedded engineered nanoparticles, i.e. "nanocomposites" are rather safe. Thus, risk research is focused on free engineered nanoparticles. It must be underlined that currently only few experiments have been done on the release of nanomaterials from products and composites [9-10]. Furthermore the results are difficult to interpret, as there is a lack of defined standards for measuring the release and exposure.

In our study we found different integration modes as to how engineered nanoparticles can be integrated into solid materials and linked to the textile matrix. We analysed the factors that might influence the unintended release of engineered nanoparticles from textiles at some time in their life cycle. We draw some first conclusions, why the design of a textile may be relevant for safety.

2 METHODS

It is a challenge to find information about used engineered nanoparticles in descriptions of commercial products. [11] analysed the largest nanoproduct data base [12] and found a "lack of information about which kind of materials are used" (p 440) and as to how they are integrated. Up to now there is no obligation to label industrial or consumer products that contain engineered nanoparticles. Thus, it is difficult to get an overview of nanoproducts on the market. On the one hand there are products labeled "nano" that are not based on nanomaterials and on the other hand there are nanoproducts that are not advertised as such [13]. Based on this information gap and other reasons described above it is elusive what kind of integration models are already on the market. Although, most textile research studies focus on the performance of the new fibre, yarn or fabric, at least some of them contain valuable information on engineered nanoparticles and integration modes. Thus, the following integration models are elaborated based on the descriptions in current research studies. In addition we did expert interviews in order to complement the integration models and to understand what factors might influence the unintended release of engineered nanoparticles during the textile life cycle.

3 NANOTEXTILES

"Nanotextiles" do fulfill functions that are based on the effects of nanomaterials. The term "nanomaterial" is a collective term for engineered nanoparticles and nanostructured material [14-16]. Nanostructured materials may contain engineered nanoparticles (e.g. nanocomposites) but may also be free of engineered nanoparticles (e.g. nanoporous polymers) [15,17] propose to apply the term "nanoparticle" only for particles with all three external dimensions in the nanoscale. [17] proposes the term "nano-object" as a collective term for "nanoparticles" "nanoplates", "nanorods", i.e. discrete pieces of material with one or more external dimension(s) in the nanoscale. Due to the unfamiliarity of the term "nano-object" we use the collective term "engineered nanoparticles" in this paper for all discrete pieces of material that have one or more external dimensions in the nanoscale.

3.1 State of technology of nanotextiles

In a survey [18] researchers and industrial experts assumed that antibacterial, self-cleaning and antistatic respectively conductive textiles, based on nanomaterials are probably already on the market. Silver (Ag) and titanium dioxide (TiO_2) were mentioned as most used nanomaterials for nanotextiles followed by SiO_2, CNT and ZnO. Examining more closely some of the advertised nanoproducts it was clarified that some of these functions are rather based on micrometer than nanometer scaled structures. Based on this survey and some expert interviews we concluded that nowadays there might be only few nanotextiles on the market already, whose functionalities are based on nanomaterials respectively engineered nanoparticles.

3.2 Integration of engineered nanoparticles in textiles

Engineered nanoparticles are integrated in the polymer during (i) the production of fibres or during (ii) the finishing of natural or artificial yarns, either by adhesion of engineered nanoparticles at the surface of the yarn or by applying coatings containing engineered nanoparticles. This paper focuses on polymer fibres containing engineered nanoparticles, in the following called "nanocomposite" fibres.

3.3 Nanocomposites

Mainly four thermoplastic polymers are used for textile applications: (i) polyester (e.g. polyethylentherephtalat (PET)), (ii) polyamid (PA) (e.g. polyamid 6 and 6.6 nylon), polyacryl (PAN), (iii) Polyethylene (PE) and (iv) Polypropylene (PP) [19]. Of course there are many more types of polymers under investigation.

The lateral cut of polymer fibres can be round, starshaped, triangular, list-shaped among others. There are also core sheath and side-by-side fibres or fibres with nanoscale diameters, so called nanofibres (Fig 1).

Depending on the type of polymer and the shape of the lateral cuts, fibres are more or less sensitive to external impacts such as mechanical stress, UV, water, sweat, microbes, solvent (organic, anorganic), detergents, heat and general material ageing processes (e.g. loss of polymerstructure, loss of softeners).

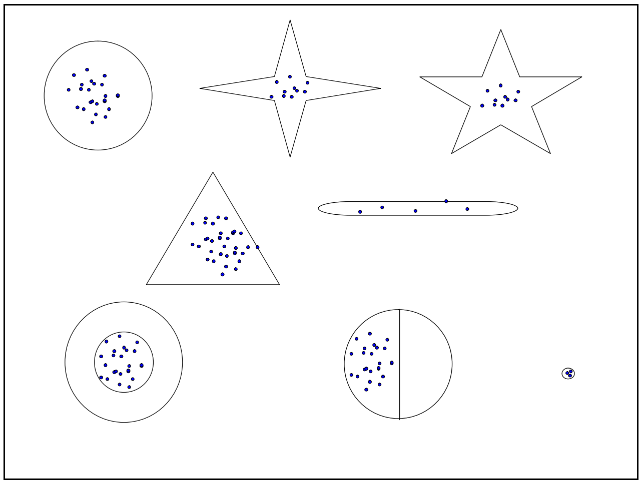

Figure 1: Different lateral cuts of polymerfibres with integrated engineered nanoparticles (left to right, top to bottom): round, star-shaped, triangular, listed-shaped, core-sheath fibre, side-by-side fibre, nanofibre. For better visualization the scales of engineered nanoparticles and nanofibres are not exact.

Theoretically, it is possible to integrate spherical metal (e.g. Ag) and oxide (TiO_2, ZnO) nanoparticles, layered silicate particles (e.g. montmorillonite ($Al_2[(OH)_2/Si_4O_{10}]\bullet nH_2O$), and carbon nanotubes (single or multiwalled carbon nanotubes) in polymer. Notably, terms such as Ag, TiO_2 and Carbon Nanotubes (CNT) and others stand for a non - uniform class of engineered nanoparticles. Individual engineered nanoparticles belonging to the same class and production batch may differ from each other by e.g. size, length, structure, impurities, functionalization and more physicochemical parameters. It is assumed that the degree of uniformity of engineered nanoparticles may also influence the quality of the nanoproduct.

The challenge is to get a homogenous dispersion of engineered Nanoparticles within the polymers, due to the tendency of engineered nanoparticles to agglomerate. Pristine engineered nanoparticles tend to agglomerate or aggregate due to their high surface area and their dangling bonds. For many textile functions the bias of engineered nanoparticles for agglomeration or aggregation is disadvantageous. Furthermore they tend to absorb moisture and oxygen that leads to a number of unwanted side-effects. Therefore engineered nanoparticles get functionalized beforehand in order to diminish their tendency to agglomerate. The idea is to bestow desired surface properties of engineered nanoparticles by influencing surface chemistry and or architectures of engineered nanoparticles without significantly altering the other desirable properties of the engineered nanoparticles (e.g. photocatalytic activity, wettability). [20] argues that the positioning of the engineered nanoparticles in the polymer is “much more reliant upon the nature of the interactions between the surfaces of the engineered nanoparticles and the constituent components than upon the bulk composition of the components themselves”(p 197)

Thus, engineered nanoparticles often become functionalized (e.g. by coating of engineered nanoparticles, by attachment of chemical groups (e.g. organic molecules) to the surface of engineered nanoparticles) in order to diminish their tendency to agglomerate or aggregate in polymer fibres or coatings and gain optimal fibre performance.

Functionalization of engineered nanoparticles also may be used to link engineered nanoparticles to fibre material. Engineered nanoparticles may be linked to the textile fibre either by a chemical covalent, ionic, hydrogen bonds or Van-der-Waal forces (decreasing strength). Apart from a few textile applications where the release of engineered nanoparticles is intended (e.g. chitosan capsules [21]), the engineered nanoparticles should be permanently bound to the textile material during the textile life cycle, for reasons of product safety and long lasting textile functionality.

4 CONCLUSION

Up to now the unintended release of engineered nanoparticles is not investigated conclusively. Knowing the different properties of polymers and shapes of textile fibres, and the varying physicochemical properties of engineered nanoparticles and their functionalization, it may be difficult to escape the conclusion that the distinction between “engineered nanoparticles embedded in solid material” and “free engineered nanoparticles” does not suffice [22]. We assume that the following factors might influence the stability of the integration of the engineered nanoparticles in nanotextiles: (i) the localization of the nanoparticle in the textile, (ii) the persistency of the polymer against potential external impacts during the textile life cycle (mechanical stress, UV, water, sweat, microbes, solvent, detergents, heat and general material ageing processes), (iii) the type of adhesion between the engineered nanoparticle and the textile material, and (iv) the physicochemical properties of the (functionalized) engineered nanoparticles (e.g. wettability, photocatalytic activity).

Thus, we conclude that the unintended release of engineered nanoparticles - at least during the use phase of the life cycle - might be influenced by an intelligent design of the nanotextiles.

In future the assumptions made in this paper have to be reinforced by experimental studies and the unintended release of engineered nanoparticles during the disposal phase (e.g. incineration, landfill) or the recycling has to be studied.

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