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REVIEW PAPER

Nanotechnology and Protective Clothing for Defence Personnel

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ABSTRACT

Defence personnel face multiple threats from different quarters, like terrorist groups and rogue nations, who own not only advanced lethal weapons but also chemical and biological warfare weapons. The present day protective clothing system used by the defence sector is vulnerable to modern weapons and also have some inherent weaknesses like high cost, bulkiness and discomfort in wearing. Nanotechnology- based materials offer a promising future in this area due to their extraordinary physical, chemical, mechanical, and electrical properties at nano-level. This paper outlines the various developments related to the application of nanotechnology in producing lightweight and comfortable protective clothing for the military personnel and also some new developments like sensor, energy storage, conductivity, and decontaminant fabrics.

Keywords: Nanofibres, nanocomposites, nano-based yarn and fabric, protective clothing, nanoparticles

1. INTRODUCTION

Military personnel on land, sea, and in the air face many complex hazards which are deliberately aimed at maiming or killing them. Hence, it is inevitable for them to wear protective clothing like body armour, chemical and biological (C&B) protective clothing, etc. At present, textile fibres such as kevlar, nomex and nylon find immense applications in protective wear garments for military personnel. High strength, antiballistic, flame retardant characteristics are some of the vital properties that make these fibres uniquely suitable for defence and other high-tech applications. In addition to the availability of high performance fibres, specialty chemicals and coatings enhance the performance of protective fabrics. Non-woven materials such as spun-bonded and melt-blown non-woven fabrics are mainly used for the manufacture of protective wears like barrier protection and fire-retardant fabrics. The advantages of using these fabrics, as against the conventional fabrics, lie in their low cost, improved barrier properties, impermeability to particulate matter, adequate strength, and comfort properties. Recently, there is a growing interest in the use of fine fibres such as micro- and nanofibres for specialist applications. The protective clothing made up of these fibres and their composites give high performance, functionality, comfort, and larger life span with less weight, size, maintenance and cost. Nanostructures and nanocomposites are being developed for the following defence applications:

- Lightweight protective clothing
- Flexible antiballistic textiles
- Chemical and biological warfare protection and self-decontaminating nanofibre fabrics
- Adaptive suits like switchable fabrics for improved thermal control, switchable camouflage.

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- Carbonnanotube polymer composite fibre (high strength).

Experiments with non-woven mats indicate that the tensile strength increases significantly with reduction of the fibre diameter, e.g., going from a 6 μm fibre to a 60 nm fibre results in a 10-fold increase in tensile strength due to increase in number of fibre-to-fibre bonds and orientation of the polymeric molecules in the fibre-length direction. Due to small pore sizes in electrospun mats, resistance to convective gas flow is large, and hence, these are an excellent choice for protective fabrics[2].Thandavamoorthy[3], *et al.* have developed a method to produce polyurethane nanofibres which can be used to trap the toxic materials. The poly lactic-co-glycolic acid (PLGA) fibre and poly (ethylene oxide)-polypyrrole nanofibres are also produced using the electrospinning technique. These nanofibres are finding applications in electrical conductive textile material development. Tsai[4], *et al.* of University of Tennessee produced nanofibres from different polymers like polycarbonate, poly (ethylene oxide), polyurethanes, polystyrene, polycaparolactone, nylon 6, and nylon 66 and the fabrics made out of these nanofibres were studied for their barrier properties against microorganisms and chemicals.

2.1 Nanotube-based Fibres and Yarns

Nanotube-based fibres can often be prepared (Fig. 2) by dispersing single-walled carbon nanotubes (SWCNTs) in surfactant solutions followed by injecting these into a rotating bath of polymer solutions like aqueous polyvinyl alcohol (PVA), then slowly pulling the fibres from the bath, enabling aggregation and alignment of the nanotubes. The intimate inclusion of CNTs in these fibres can completely change their mechanical and electrical properties. Unlike classical carbon fibres, the nanotube fibres can be bent to maximum extent without breaking. Their obtained elastic modulus is 10-time higher than the modulus of high-quality bucky paper, a thin mat obtained by drying SWCNT[5].

Several researchers have attempted to produce CNT-polymer blends with moderate levels of alignment with nanotubes. Jalili[6], *et al.* of National Textile Centre (NTC), USA, have produced continuous yarns of up to 30 cm length of pure CNTs, with a diameter of about 200 nm, by drawing super-aligned arrays of CNTs. The process was similar to the process of production of silk from a silk cocoon. It was also reported that the tensile strength of the yarn and electrical conductivity (after the yarn was used as a filament in a vacuum chamber) were increased.

Zhu[7], *et al.* directly synthesised long ropes of nanotubes using an optimised CVD process in a vertical furnace. The process entailed the catalytic pyrolysis of *n*-hexane containing ferrocene and thiophene and was reported to produce long ropes of SWCNTs at rates of up to 0.5 g/h and a purity of up to 95 per cent. The tensile strengths of the nanotube fibres produced by this method were almost 5-time higher than those of the nanotubes produced by other methods. This would yield nanotube-based ropes that could be utilised as passive materials in fabrics with very less processing effort.

Ericson[8], *et al.* produced well-aligned macroscopic fibres composed solely of SWCNTs by the conventional wet spinning method using fuming sulphuric acid. Such neat SWCNT fibres produced, possessed good mechanical properties, with a Young's modulus of 120 ± 10 GPa and a tensile strength of 116 ± 10 MPa. The above values can be compared with laboratory-grade PBO fibres used in ballistic protection material

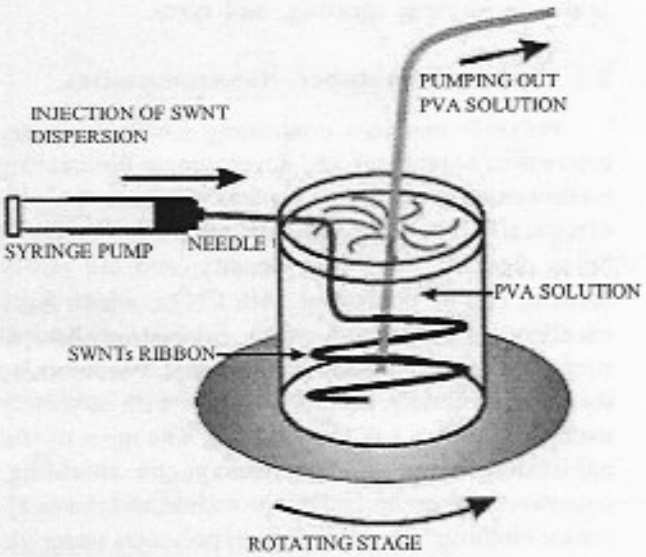


Figure 2. Preparation of nanotube-based fibres from SWCNT.

Most manufacturers of CNTs mention this as one of the applications for their products. Dynamically tunable camouflage materials would be an invaluable aid to defence operations, allowing personnel and equipment to achieve highly visible or totally concealed presence, depending on the demand of the situation. Electrochromic materials offer one way towards achieving this. DeLongchamp and Hammond[13] report a high-contrast electromeric nanocomposite material based on poly (ethyleneimine) and Prussian blue nanoparticles. It is claimed that a fully switchable reflective tricolour space coating has been produced. This material has obvious applications in dynamically tunable camouflage in the visible spectrum.

3.3.1.2 Ballistic Protection

For body armour and vehicle liners, woven materials, such as kevlar, nomex, are commonly used. It is likely that electrospun nanofibres could be useful in such applications. It is reported that spun CNTs with extreme mechanical properties could be used for developing these types of materials. Lee[14], *et al.* reported a new liquid body armour based on nanotechnology. This was produced by impregnating kevlar-based conventional body armour with a stress-thickening fluid (STF) composed of colloidal dispersion of hard spherical silica nanoparticles of about 450 nm size in a polymer solution of polyethylene glycol. When this shear thickening fluid was impregnated into the conventional kevlar, the ability of the material to absorb energy was greatly improved. The ballistic performance in terms of absorbed energy is more than double so that four-layers of kevlar impregnated with the STF could absorb as much energy as absorbed by 10 layers without the STF. The mechanism proposed is that at high volume fractions, high shear stresses cause the suspended colloidal particles to form hydroclusters. Hydrocluster formation leads to a viscosity increase that can, at sufficiently high particle loading, result in a solid-like response, which is termed discontinuous shear thickening. In this line, kaolin clay platelets of about 500 nm diameter-based STF was also reported by Brian[15], *et al.* In terms of practical application, this will lead to much more flexible armour with equivalent ballistic protection and somewhat reduced total weight[16].

3.3.1.3 Fire-retardant Fabrics

Conventionally, chemical additives (halogenated hydrocarbons) are being used to reduce the flammability of fabrics but these have a number of side effects. If the fire occurs, the halogen will produce highly toxic and corrosive combustion gases and also may create several environmental problems.

Nanometer-sized clay particles (often montmorillonite) finely dispersed in selected polymer matrices are used as the reinforcement phase and provide enhancements in stiffness, toughness, tensile strength, thermal stability, gas-barrier properties, and importantly, flame-retardant character. The thermal properties of polymer nanocomposites are improved so that melting and dripping are delayed and the rate of burning is reduced by more than half. Further advantage is that the addition of the clay nanoparticles improves the mechanical properties of the fabric significantly, which can be utilised to reduce the thickness and weight. Two common types of morphologies exist for these nanocomposites: (i) intercalated, in which the polymer or monomers infiltrate the ordered array of silicate layers, and (ii) exfoliated, which results when the silicate layers are completely delaminated and finely dispersed within the polymer network. Dispersion of silicate layers in a polymer is difficult. For dispersion, compatibilising agent, a molecule constituted of one hydrophilic and one organophilic function, is commonly used[17].

3.3.1.4 Chemical/Biological Protective Nanocomposites

The protection of the soldier from exposure to hazardous chemicals, such as chemical warfare agents, is essential to mission accomplishment in today's battlefield and in that of the future. This protection is currently accomplished using an activated carbon system, using semipermeable material systems, and using impermeable barrier materials.

The activated carbon system is used in protective overgarments and affords protection by adsorbing hazardous chemicals. The impermeable barrier materials consist of rubber, coated and multilayer laminate fabrics found in gloves, boots, and for special purposes

and good reproducibility found to have high potential for many applications, such as electromagnetic wave absorbers, electrode materials, tunable micro-devices, and so on without the addition of poisonous sulphur gas promoter.

Srivastava,[27] *et al.* of Banaras Hindu University in collaboration with Rensselaer Polytechnic Institute, USA, have developed a CNT-based filter. Using the CVD method, the scientists were able to make hollow macrotubes consisting of radial arrays of CNTs. These tubes, with a wall thickness of around 300 nm, have sufficient mechanical strength to act as filters. The filters find applications in the elimination of multiple components of heavy hydrocarbons from petroleum in a single-step filtering process, and the filtration of contaminants such as *E.coli* bacteria or the nm-sized polio virus from water. These macrofilters can be cleaned for repeated filtration through ultrasonication and autoclaving. Shrivastava[28], *et al.* of the same University reported the preparation of silver nanoparticles in the range of 10-15 nm with increased stability and enhanced antibacterial potency.

Joshi[29], *et al.* of the Indian Institute of Technology Delhi, New Delhi, prepared polyurethane/clay nanocomposite and coated there on nylon fabric to improve the gas barrier property. The coating reduced the hydrogen gas permeability by about 36 per cent at clay content of 3 per cent Wt as compared to neat polyurethane coating at the same thickness. This method of coating has military applications like coatings for hot air balloons, floating systems, and other aerial delivery systems.

5. CONCLUSIONS

Development of nanotechnology-based protective clothing for defence personnel is one of the important areas where all the major powers of the world are making efforts to do research and develop new materials. Ballistic clothing, barrier clothing against chemical and biological materials, self-decontaminant fabrics, and biomimicked fabrics based on nanotechnology are the thrust area of research in this field.

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