- Microsensors for body and brain sensing, environmental and situational awareness, integrated into a smart suit or a smart helmet.
- Wearable and/or flexible displays for visual feedback auxiliary supports: Flexible/rigid textiles for additional strength, exoskeletons, and robotics to assist the human tasks.

2. NANOFIBRES

Electrospinning is a cheap and relatively simple technique to produce nanofibres. This technique, though very old, has regained interest since it enables the production of cheap nanostructures. This process (Fig. 1) mainly consists of a dc power supply used to generate high voltage in the order of 25–85 kV between a polymer solution to be drawn out into nanofibres and a grounded collector plate. The polymer solution to be drawn is stored in a syringe which has a thin capillary tube mounted at one end. The syringe is typically driven by a syringe pump at a specific flow rate. The spinning process is carried out by pumping the polymer solution to the end of the capillary tube such that it forms a small pendant or hemispherical surface. Then, a high voltage is applied between the polymer solution and the collector plate placed at a distance from the capillary tube. The electrostatic forces generated as a result of this electric field act against the surface tension and viscosity of the solution, thereby transforming the pendent like shape or the solution into a conical shape called the Taylor cone. Under further influence of the electrostatic forces, the polymer solution forming the Taylor cone stretches into a fine jet of fibre that travel towards the grounded collector plate and finally gets deposited on it. Continuous deposition of such fibres on the collector plate results in the formation of a non-woven mat having high surface area-to-volume ratio, carbon nanotubes (CNTs) can also be prepared using this process[1].

Electrospun nanofibre fabrics have several potentially attractive features. Some of these are: (i) softness potential of acting as a barrier against microorganisms and fine particulates; (ii) a potentially good strength per unit weight; and (iii) a high surface energy that indicates a potentially good vapour transmission rate.

Nanofibres can be used as nonwoven mats but can also be spun into yarn. The following applications are being developed:

- Nano filtration and absorption-catalytic breakdown (catalytic active nanofibre, or nanofibres with a catalytic coating, chemical and biological breakdown).
- As sensors, because the large surface area, are sensitive to absorption and subsequent change. for example, the electrical resistance (polymer conductive nanofibre).
- Structural applications, reinforcement fibre, e.g., for antiballistic application.
- Insulation
- Selective gas permeation (breathing, chemical and biological protective fabrics).

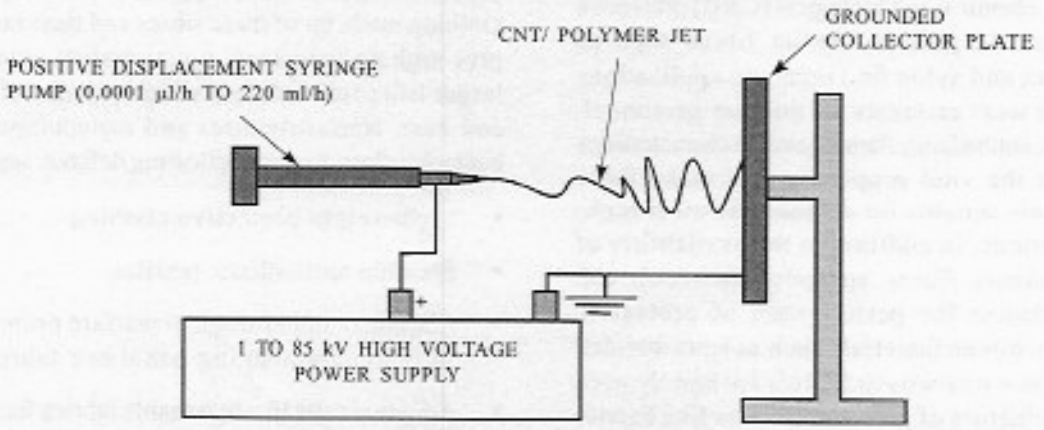


Figure 1. Schematic diagram of electrospinning unit.

which possess a Young's modulus of 138 GPa and a tensile strength of 2.6 GPa.

The fibres produced by all the above methods possess very good electrical and thermal conductivity values apart from their interesting mechanical properties. Efforts are now being made to weave these fibres into macrostructures which can be used for a variety of applications, like actuator and sensor fabrics for the defence personnel.

3. POLYMER NANOCOMPOSITE FIBRES AND YARNS

Nanocomposites consist of a matrix material, usually a polymer, with a dispersion of nanoparticles/ fibres. Several nanoparticles like carbon nonofibres, SWCNT, MWCNT, nano-TiO_2, nano-Al_2O_3, and aluminosilicate nanoclay were dispersed in a polymer matrix, instead of using conventional fillers, to produce novel composites with enhanced mechanical, electrical, and thermal properties. For example, as little as 1-5 per cent weight of nm-sized clay particles in cross-linked resins can provide big improvements in mechanical and thermal properties; reduced permeability to gases, moisture, and hydrocarbons; and increased flame resistance to textile polymers[9]. Nanocomposite materials have a wide range of applications in the fields of aerospace, ESD/EMI shielding, adhesives, paints, gas sensors, automobile seats, packaging, sporting, and tyres.

3.1 Carbon Nanotubes–Nanocomposites

Polymer matrices containing CNTs is a very active area of research and development for creating multifunctional materials. Polymers which are normally electrically insulating but have other advantages of being flexible, have low density, and are easily formed, can be combined with CNTs, which have excellent electrical conductivity, extreme mechanical strength, and high thermal conductivity. By combining these two materials, a nanocomposite with extremely useful properties can be obtained. The most useful application areas are electromagnetic shielding, microwave absorption, ballistic protection, and chemical-sensor clothing[10]. A wide range of polymers materials such as poly(vinyl alcohol), poly(methyl methacrylate), poly propylene, polyethylene, polyethylene terephthalate, etc, have been used with CNTs to form films, fibres, and bulk composites through different spinning technologies like meltspinning, solutionspinning, and electrospinning[11].

3.2 Porous Nanocomposites

There are several types of porous nanocomposites. The simplest include foam with a homogeneous matrix containing nanometric pores, i.e., a nanoporous material, whereas more complex materials may include nanoparticles or nanotubes dispersed in a matrix which may contain pores of conventional or nanometric dimensions. A significant disadvantage of conventional porous polymer foams (e.g., polyurethane) is that the large surface-to-volume ratio increases the rate of heat and gas release in the case of fire. By introducing nanoparticles like clay, rate of burning can be significantly reduced. This material finds applications in defence as shock-absorbing materials, acoustic absorbents, and as vehicle seats[12].

3.3 Defence Applications of Nanocomposites

3.3.1 Smart Uniforms

This concept of smart uniform for soldiers has come up with the advent of nanotechnology. Under this concept, it is proposed to have an all-impact suit enabled by nanomaterials combined with micro- or macrofibres, offering protection against bullets, fragment of grenades, bioagents, chemical agents, and the influences in combination with the physical status of the body (insulation, ventilation, local cooling) of a soldier. Efforts are being made to produce a suit with integrated chemical and biological sensors and nanofibre networks with absorbing, deactivating, and decontaminating capacity. Likewise, efforts are also underway to use a carbon fibre and a polymer composite to produce a lightweight suit and a helmet for ballistic protection. The following developments have taken place in this concept.

3.3.1.1 Signature Reduction

This is a highly classified field of application, although it is obvious from allusions in the literature that a lot of work on developing camouflage materials based on polymer nanocomposites is being done.

(e.g., depot storage/demolition/explosive ordnance disposal ensembles), which afford protection by acting as physical barriers to chemicals. However, these materials inherently possess either cost or logistic barriers, which make their fielding undesirable unless a catastrophic effect is eminent. A lightweight, low-cost, low-packing volume, chemical and biological protective barrier material would make collective protection feasible for conventional chemical and biological protective clothing and shelter systems, therefore enhancing the safety of soldiers during unpredictable chemical and biological attacks. Nanocomposites[18,19] based on clay, MgO[18] and TiO_2[19] have been developed which give excellent protection as well as operational advantage to the soldiers. This increase in barrier properties was accomplished without significantly changing the physical properties of the polymers.

3.3.1.5 Self-cleaning, Healing, and Decontaminating Fabrics

Self-cleaning fabrics containing TiO_2 nanoparticles have been developed based on their photocatalytic ability of oxidising dirt and other contaminants. These type of fabrics can be put to both military and civilian uses. It is reported that the textile substrates like cotton, wool, polyamide and polyester were pre-treated with RF-plasma, MW-plasma or vacuum-UV irradiation in such a way that negatively charged TiO_2 chelating groups, such as carboxylic groups, are introduced by the pre-treatment methods. Such TiO_2-treated materials showed self-cleaning activity under daylight environment[20,21]. Microbial protective clothing have been prepared by coating military garments with silver nanoparticles. These coatings in addition make the fabric self-wound healing, water-repellent, and dirt-repellent. Research is also going on to prepare the chemical and biological protective clothing with self-decontamination and drug-delivery characters. The decontaminants like nanometal oxides (MgO, Al_2O_3) along with activated carbon and antibiotics in the form of nanocoatings is being explored for this purpose[22].

3.3.1.6 Sensor and Energy-storage Fabrics

Finishing conventional textile materials with nanoparticle can convert conventional textile materials into sensor-based materials. If nanocrystalline piezoceramic particles are incorporated into fabrics, the finished fabric can convert exerted mechanical force into electrical signals, enabling the monitoring of bodily functions, such as heart rhythm and pulse, if these are worn next to the skin. The fabrics woven with CNTs can be used as energy-storing devices and can be used as next generation e-textiles. Several defence research organisations are contemplating to incorporate these technologies for developing smart soldier uniforms[23].

4. PROTECTIVE TEXTILE-BASED NANOTECHNOLOGY RESEARCH IN INDIA

In India, a larger number of research institutions are actively engaged in the nanotechnology research. The research in this particular field of protective clothing based on the above technology is limited. However, some of the nanotechnologies developed, which can be extended for protective clothing development, are summarised. Scientists at the Jawaharlal Nehru Centre for Advanced Scientific Research (JNCASR), Bangalore have developed several methods of producing CNTs, namely, by breaking down metallocene-hydrocarbon mixtures at high temperatures in the absence of air (a process known as pyrolysis), by *in situ* formation of metal nanoparticles from the metallocene which could act as a catalyst to produce bundles of high quality aligned CNTs and organometallic precursor routes to CNTs and their aligned bundles[24]. A CNT-based flow sensor was developed by a group of researchers at the Indian Institute of Science, Bangalore, based on the observation that a fluid flowing past a nanotube bundle gives rise to a potential difference across the bundle[25].

Scientists at the Defence Materials and Stores Research and Development Establishment (DMSRDE), Kanpur, have established CNTs Production Unit and synthesising non-aligned, quasi-aligned, and aligned CNTs with a batch size of 50 g using a fast synthesis process. The produced CNTs are being explored for applications as electro-magnetic wave absorbers, composites, gas sensors, flow monitors, field emission devices. Mukhopadhyay[26], *et al.* from DMSRDE produced microcoiled carbon fibres with high yield

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