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Functional clothing— Definition and classification

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Functional clothing represents the evolutionary segment of the technical textiles market, representing an area where clothing crosses the conventional boundaries and integrates with the domains of medicine, biotechnology, nanotechnology, physics and computing among others, to meet the multifaceted and complex requirements of the user. Functional clothing by definition is user-requirement specific and designed or engineered to meet the performance requirements of the user under extreme conditions. A variety of functional clothing products are available in the market as protective clothing, medical clothing or sports clothing, even though little information is available regarding the principles employed in their production. Functional clothing in fact has never really been systematically defined or classified, unlike technical textiles. In this paper, a functionality-based classification has been proposed with six classes, comprehensively covering most logical types of functional clothing that are in use or are under development. Each distinct class would have similar principles governing the design of products covered under it, even though the final products may find application in a variety of fields, e.g. protective functional clothing may find an application as protective military armour, as sports armour or as protective surgical gowns for the doctors. Principles that characterize each class and differentiate it from the others have been highlighted. As newer technologies are being developed, new and innovative products and possibly new classes will keep on emerging in this field to meet the requirements of consumers.

Keywords: Functional clothing, Medical clothing, Protective clothing, Sportswear, Technical textiles

1 Introduction

Functional clothing is a relatively new and exciting segment of the technical textiles group — one which is receptive to new product developments & technologies and abounding with niche applications. The emergence of performance clothing has been fuelled by recent breakthroughs and advances in technical fibres & fabrics and advances in garment manufacturing technologies. A lot of technologies originally developed for military applications have also become available in the public domain and form a major constituent of this field. Viability of new fibres, fabrics or finishes is often checked with an eye on their application in functional clothing design, underlining the 'evolutionary' segment of textiles.

The field of functional clothing is wide and diverse with each functionality having its own specifications, material requirements, consequent technologies and processes. Much of the technology used is amongst the most sophisticated available at any given point of time. End use applications are diverse and often quite complex, ranging from life saving and hostile environment responsive to those improving the quality of life. Owing to its evolutionary nature, the information available on the subject of functional clothing is fragmented and generally protected. There is confusion about what really constitutes the domain of functional clothing as the domain has never really been defined or classified.

2 Definition

All clothing is known to perform multiple functions – from aesthetic to basic protection from the elements. 'Functional clothing' can therefore be defined as a generic term that includes all such types of clothing or assemblies that are specifically engineered to deliver a pre-defined performance or functionality to the user, *over and above* its normal functions. Such clothing would normally be made from a mix of innovative materials, and functionality in this case would imply the added value or function that a garment is expected to perform. It can be clothing that protects individuals who are exposed to life threatening or hazardous environments during work or during sporting activities; or that can facilitate movement and body balance in physically challenged individuals or that enhance stamina or reduce fatigue in sports people. It can also be clothing that performs a purely aesthetic function like enhancing body shapes. Functional clothing can have electronic functionalities with applications in communication and telemedicine. Functional clothing assemblies are ergonomically designed so as to have a minimum inhibitory effect on movement and provide

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maximum comfort and performance to the user. Normal aesthetic considerations are often overridden in favour of performance.

3 Classification of Functional Clothing

Standard classification used for technical textiles, such as Protech (protective textiles), Sportech (sports textiles) and Meditech (medical textiles) covers primarily the materials (textiles) and not usually the end product, unless the product get used in that form for example in case of geotextiles. Development of products using these materials or textiles for specific end uses opens a completely new domain of intervention with overlaps in other emerging technologies and domains. When applied to apparel, the new products cover a vast and diverse realm collectively termed as 'Functional Clothing'. Design and development of functional clothing products is driven by the choice of materials, as defined by the social, psychological or physiological requirements of the user; choice of technologies as defined by desired functionality; and ergonomic considerations, assembly methods, sizing and fit. The author is proposing a system for classification of functional clothing based on broad design parameters used in development of products for a particular functionality.

Six classes, comprehensively covering most logical types of functional clothing, that are currently in use or are under development, have been proposed (Table 1). Each distinct class may have sub-classes with similar principles governing the design of products within that sub-class, even as the final products may find application in a variety of fields, e.g. protective-functional clothing may find an application as protective military armour, as sports armour or in surgical gowns for the doctors. The proposed classification, however, does not cover all the areas where functional clothing is required but rather only those where products are already available or are in the process of being developed. Further, while the classes are distinct in terms of functionality and therefore the principles of design employed, materials and processes may be common across the classes depending on their field of application. Principles that characterize each class and differentiate it from the others are highlighted.

The proposed classification will help illustrate this argument further. As newer technologies become available, new and innovative products and possibly new classes will keep on emerging in this field to meet the requirements of consumers.

3.1 Protective-functional

Protective-functional represents the largest and most diverse segment of functional clothing. The functionality of clothing in this case can make the difference between life and death for the user; at the very least, it can allow people to work in and around hostile environments, improve the quality of life and prevent or reduce injuries. The protective functionality can be sub-classified into 3 categories based on the nature of the threat from which protection is required. The technical requirements in each case are quite specific and distinct.

3.1.1 Environmental Hazard Protective

The nature of threat in this case is extreme environmental conditions (natural or man-made), such as extreme heat or cold, fire, rain, snow, dust, wind or

Table 1—Six proposed classes for functional clothing

Class	Subclass	Description
Protective-functional	Environmental hazard protective	Protection against extreme heat or cold, fire, rain, snow, dust, wind or UV exposure
	Biological, chemical and radiation hazard protective	Protection against ingestion, penetration or skin contact of hazardous chemicals, toxic gases, body fluids, germs or radioactive particulate matter
	Injury protective	Slash and cut protection, ballistic and blunt impact protection
Medical-functional	Therapeutic and rehabilitative	Pressure garments for lymphatic and venous disorders, scar management
	Bio-sensing	Monitoring of physiological parameters, heart rate, blood oxygenation, body temperature, telemedicine applications
Sports-functional	-	Performance enhancing, fatigue reduction, body shaping to reduce drag
Vanity-functional	-	Body shaping, support and contouring for enhanced appearance
Cross-functional assemblies	-	Multifunctional performance, protection, life support, comfort, communication
Clothing for special needs	-	Enabling clothing for elderly, infants, and disabled

UV, against which protection is desired. The critical design requirement here is to protect the body from exposure to extreme elements in the environment (say temperature) while at the same time facilitating the transport of metabolic heat and moisture from the body. Essential requirements would be good insulation with lower weight and bulk and ergonomic design as per mobility requirement of the application, for example scuba diving suits, mountaineering suits and fire fighters suits.

3.1.2 Biological, Chemical and Radiation (BCR) Hazard Protective

BCR hazards are also present in the environment but the nature of threat represented by them and the consequent protection requirements are totally different from the first category. The critical design requirement in this case would be to create a barrier to prevent the ingestion, penetration or skin contact of hazardous chemicals, toxic gases, body fluids, germs or radioactive particulate matter. Specialized coatings and laminates are the main materials used in these products. Often such clothing will be completely closed, and may therefore require cooling, breathing or metabolic waste removal functions to be built into the clothing system itself.

Clothing for doctors and health workers constitutes a major portion of biological protective clothing, while industrial and military clothing are designed to provide protection from chemicals and radiation hazards. Clean room clothing on the other hand is used to prevent the escaping of submicron particles from the human body to the environment to prevent contaminating the product or environment in which one is working[1]. The principle of design for these products would also be based on barrier properties, but in the reverse direction.

3.1.3 Injury Protective

Nature of threat in this case is in the form of mild to fatal injuries caused by ballistic, blunt and mechanical impact or cut and slash hazards from a variety of sources. Principle of protection in such cases is primarily material based and that of impact resistance.

Ballistic injuries are high impact injuries and anti-ballistic clothing is the oldest form of protective clothing known to man. This area is well studied and has kept evolving to keep pace with developments in weaponry. Multiple layers of high strength fibres, ceramics, metal sheets and composites are used to obtain soft/ semi–hard/ hard armours with an optimum combination of light weight and high protection, depending on perceived nature of hazard.

Blunt impact injuries can be caused under a host of circumstances. Some are caused during extreme sports such as motor biking and snow boarding. Others may be caused in man - man collisions during sporting events like rugby or football, or as high speed ball injuries during ball games like cricket or hockey. Law enforcement personnel may sustain blunt impact injuries caused by projectiles and blunt objects. Again a variety of soft/ semi–hard/ hard armours and guards are used for protection. In this case, however, armour consist of shock absorbing EVA (ethylene vinyl acetate) and PU (polyurethane) foams in combination with energy-dissipating hard sheets made from polymers or composites. A recent breakthrough has been in the form of nanotechnology based shear thickening fluids or 'liquid armour'. These are smart polymers that are light weight, flexible, and fluid to begin with but harden on sudden impact. They conform to the body contour easily and keep the wearer comfortable.

Protective clothing is also required for protection from occupational cut and stab injuries caused during meat cutting, working with chain saw, glass and knives. Law enforcement personnel, emergency workers and forest workers also face these hazards. High strength fibres like steel, aramid or HDPE, woven into light weight fabrics are used to design jackets, gloves, aprons, sleeves, guards and inserts for such applications. These fabrics treated with shear thickening fluids create puncture and stab resistant clothing which is flexible and light in weight.

3.2 Medical-functional

For a long time, basic pieces of clothing such as patients' and surgeons' gowns, aprons, and gloves are called 'medical clothing'. The primary functionality of these clothing being protection from body fluids, germs, etc. Such products are covered under the protective functionality. Medical functionality now encompasses much wider and sophisticated applications to cover therapeutic, bio-sensing, emergency care and rehabilitation activities as discussed below under two sub classes.

3.2.1 Therapeutic and Rehabilitative Clothing

Pressure therapy imparted through compression garments is a well-established line of treatment for hypertrophic scars, burn injuries, venous and lymphatic disorders[2-7]. Use of pressure garments

brings about an increase in venous blood flow in the lower extremities, thus helping with venous thrombosis. Pressure is imparted by use of stretch fabrics containing elastic yarns. The variety and level of sophistication of materials and technologies used in their production have improved tremendously since their use first started in 1970s.

A more recent and lesser known application of pressure therapy is in rehabilitation clothing. This class of clothing is generally custom made for patients with unusual body dimensions or some bodily function impairment. It is based on a combination of the science of proprioception (the unconscious perception of movement and spatial orientation arising from stimuli within the body itself) and targeted skeletal support technology[8]. Appropriately designed clothing create a positive anatomical change in the body, increase body strength, enhance motor skills and/or provide support to paraplegics, neonates, elderly, pregnant and nursing women and patients with motor disabilities.

3.2.2 Bio-sensing Clothing

This is one of the most recent and exciting categories of medical clothing emerging out of integration of electronic sensors into clothing. Such clothing worn next to the skin is used to map critical physiological parameters like heart rate, blood oxygenation, pulse rate, core body temperature, etc[9]. Developments in miniaturization of electronics in flexible and stretchable form[10] so that they can be worn on the body are driving this field.

Future research is targeted towards development of more sophisticated but smaller pieces of textile based material that cover only a small part of the body at a time. Such items are not covered under medical clothing but are classed under devices. These are used sometimes for remote critical care (telemedicine) or in fitness assessment of sports persons. Textile patches can act as biochemical sensing and processing units and take measurements from fluids like sweat and blood[11]. Carbon based electrochemical sensors, printed directly on the elastic of men's briefs can continuously monitor amount of hydrogen peroxide and NADH (both associated with numerous biomedical processes) on the skin [12]. Bio-sensors to measure the *p*H and conductivity of sweat and immuno-sensors to detect the presence of specific proteins in fluid sample, which can be integrated into wound dressings or bandages, are in the offing[11]. Other clothing based devices for orthopedic applications are used to provide medial and lateral support to sore or sprained body parts or arthritic joints. Injured body parts, particularly stiff, weak or sore ankles, are supported by flexible splints made from neoprene, elastic fabric, a combination of soft and hard parts and air or gel filled bags. In emergency services, cardiopulmonary resuscitation (CPR) vests are used on patients transported by an ambulance[13,14].

3.3 Sportswear

Sportswear is the most versatile and fastest growing segment of the performance clothing market. Dramatic lifestyle changes, a rapidly aging population, increasing sports participation and health consciousness have created a huge demand for functional sports apparel. Accordingly, a range of value-added clothing with properties like temperature regulation, moisture management, stretch, odor reduction and light weight is available in the market for everyday sports wear. While these clothes may have multi-functional properties, they do not fall in the category of functional clothing.

Sports-functional clothing as a class represents those performance enhancing clothes that help sportsmen compete at the cutting edge of performance. Two principles primarily govern the design and engineering of these sportswear, i.e. application of compression on specific muscles to increase blood flow and application of principles of a aerodynamics to reduce wind or air drag in high speed sports. Both principles can be used in combination or individually, depending on the requirements. Unlike the other classes of functional clothing, aesthetics is also an important design criterion in this category.

Compression

There are many possible mechanisms via which compression clothing enhances performance in power-based activities. Clinical studies show that augmented *proprioception* could be responsible for an improvement in technique, while reduced oscillatory displacement of muscles may be promoting enhanced neurotransmission and mechanics at the cellular and molecular level[15]. It additionally enhances lactate removal, improve oxygen supply, and improve recovery following exercise and training. Psychological factors (feel of the garment when wearing compression garments [16-23]) are also perceived to improve performance.

Aerodynamics

Aerodynamic drag because of wind or air resistance is reduced through a number of mechanisms such as manipulation of surface morphology of the material;

reducing air and/or water permeability of fabric; and altering shape of patterns and placement of seams and fasteners on the clothing. Even a small reduction in wind or water drag can result in a significant performance increase[24,26] in speed sports like sprinting, speed skating, cycling, ski jumping and swimming[26].

3.4 Vanity Clothing

This is a unique category which has never before been classified under functional clothing as its only function is to enhance body aesthetics. A new awareness of health and body across the world as well as a large ageing population has fuelled the growth of this segment in the last few years. Men and women with ageing or less than ideal body shapes use these garments as an instant and non-surgical method of body shaping. Even though the primary function of vanity clothing is to enhance body appearance, the principles governing their design and production are no different then those used for other functional clothing in general.

The principle of vanity clothing is to compress, lift or support certain body parts preferentially in order to create an artificially sculpted and perfectly shaped body. A complex combination of preferential compression, invisible support, padding, molding, wiring, special seams and special construction techniques are used to achieve the desired properties. Pants, bras and various undergarments (invisible under outer clothing) are available that can lift sagging parts and have a slimming and flattening effect on stomach, waist, hips, thighs, buttocks and back as desired.

3.5 Cross-functional Clothing Assemblies

This class of functional clothing represents some of the most sophisticated clothing assemblies which are expected to perform across several complex functionalities at the same time, e.g. military clothing and space suits. They make use of varied materials ranging from metals, ceramics, membranes, composites, high performance polymers as well as electronic textiles to build functionalities across multiple classes. Several interdisciplinary expertise areas come together to create such clothing system. Research continues towards developing systems which are more efficient, light weight and comfortable.

Military clothing has to provide protection from ballistic injury as well as hazards of environmental, nuclear, chemical and biological nature. It must have compatibility with other gear elements like helmet, gas mask, ballistics gear, survival vest, cooling systems and hand and foot gear; allow for communication (GPS, monitoring and discreet devices) and at the same time be comfortable in extreme postures and activity for very long periods of time.

A modern day space suit is an extreme example of how complex a clothing system can get. Its made up of upto 18,000 odd parts & up to 11 layers, and has to host everything that an astronaut needs to stay alive —oxygen, water, temperature control and carbon dioxide removal; provide stable internal pressure; shield against radiation; protect against micrometeoroids and so on.

3.6 Clothing for Special Needs

This class represents a class of functional clothing that is meant to improve the quality of life for that section of human population, whose body shape, size, mobility or dexterity is significantly different from that of so called “normal people”. These include pregnant and lactating women, infants, children, elderly, disabled, autistic, paraplegics and so on. Some of these conditions are temporary such as pregnancy, lactation or infancy and their requirements not as critical as those of people suffering from permanent ailments. Studies have shown that these groups are exceptionally sensitive about their clothing and general appearance. The needs of each group are distinct and different from those of others. Thus, there is a need to design clothing specifically engineered to their requirements.

Design considerations would include changed body shape, limitations of strength & mobility, as well as the psychological and social needs. Clothing that looks and feels good and is comfortable can go a long way in improving the quality of life for these groups with special needs. Clothing for aged, autistic children and paraplegics are available internationally.

4 Conclusion

The classes of functional clothing proposed above are not mutually exclusive and there is bound to be an overlap in the requirements and technologies employed. However, they provide a clear idea of the distinct applications to which functional clothing caters. New applications and new products continue to appear as this field evolves and grows rapidly on a day to day basis.

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