An overview of military textiles

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Developments in the weapons and surveillance technologies are prompting innovations in individual protection equipments and battle-field related systems and structures. Besides conventional requirements such as durability to prolonged exposure, heavy wear and protection from external environment, the protection is sought from ballistic projectiles, fire, CBN (chemical, biological and nuclear) weapons and surveillance and detection systems. It is a challenge to the "system" designer to satisfy the conflicting requirements within the constraints of physiological requirements, logistics, technological limitations and the cost. This article gives an overview of the requirements, design considerations, developments and innovations related to the textile usage in the military applications. The examples and citations are mostly in the context of the United States Army.

Keywords: Ballistic projectile, Biological weapon, Camouflage, Chemical weapon, Nuclear weapon

1 Introduction

The fall of a super power has resulted in decreased U.S. defense spending, but it has certainly not turned this planet into a place of everlasting peace and bliss. The potential remains for the misunderstandings, security impasses and internally unstable military powers. The hostile states can emerge with little warning.

Although modern wars are being increasingly fought more or less by remote means as evidenced by the recent examples, a combat soldier is still indispensable. Despite hundreds of sorties, U.S. fighter planes with their ultra-modern radars, sensors and state-of-the-art means of delivery could not locate the mobile missile launchers of Iraq during the Gulf war and not a single one was destroyed from the air. Modern trend in war fighting needs to have small teams of highly trained, well-equipped combat troops supported by the state-of-the-art weaponry and communication systems. This requires even more dependable protection systems as each troop is important due to smaller size of the teams.

By the turn of this century, there will be over 20 countries with ballistic missiles, 9 with nuclear weapons, 10 with biological weapons and up to 30 with chemical weapons. Besides direct threat to the national borders, the opportunities to use military force will be provided by the hostage rescues, punitive action against terrorists and the states supporting them, enforcing sanctions, demands laid by the narcotics policy and immigration regulation.

2 Role of Textiles in Military

Textiles are widely used in the military. The U.S. Defense Department has about 10,000 items in its inventory made partially or entirely from textiles. About 300 of these items are regarded as "combat essential", including uniforms, protective clothing, parachutes, sweaters, socks, gloves, coveralls, sand bags, sheets, blankets and hospital supplies. The applications of military textiles may be divided into two categories: (i) personal protective clothing and individual equipment (battle dress uniforms, ballistic protection vests and helmets, chemical protection suits, belts, ropes, suspenders and field-packs), and (ii) defense systems and weapons (tents, parachutes, shelters, tarpaulins and textile composites). A detailed list of military textile and apparel items is provided by Adanur.

2.1 The Soldier as a System

The soldier along with his supplies, clothing, weapons and accoutrements is treated as a system (Fig. 1). The soldier system efforts are based on the Soldier Modernization Plan of the U.S. army. It includes improved individual equipment, clothing, weapons and subsistence items to enhance his
overall effectiveness and survivability on the battlefield. Soldier system items include several related programs that respond to the changing threat requirements and advances in state-of-the-art technology. Combat clothing and individual equipment (CIE) is one of the four main areas in which the Soldier Enhancement Program (SEP) projects are focused. Some textile related projects include Enhanced Load Bearing Vest, Inconspicuous Body Armor, Second Generation Extended Cold Weather Clothing System (ECWCS) and Amlor Crew/Infantry Masks. Mid-term research and development CIE efforts are focused on the light weight equipment, ballistic and laser eye protection and improved chemical protective clothing. Long-term efforts include 21st Century Land Warrior (21CLW), which will identify less mature technologies to meet longer-term soldier deficiencies.

2.2 Textiles for Personal Protection

For personal protection, the requirements can be divided into four categories: (i) battle-field: protection from chemical warfare agents, flames, thermal radiation, ballistic impacts and detection (camouflage and low-noise clothing); (ii) environmental: water-proof, snow-shedding, wind-proof, air-permeable and insulative. It should also deny entry to insects; (iii) physiological: minimum heat-stress, low weight and bulk, moisture-vapor permeability, air-permeability and insulative; and (iv) physical requirements: low weight and bulk, durability, soil-resistance and maintenance.

Not only do these requirements overlap, but they also contradict each other at various levels. All of them are important, but the means to fulfill these requirements are not simple and straightforward. Improvement in one aspect generally results in the deterioration of the other. For example, protection from environment invariably results in compromises with soldier's comfort, causing heat stress and fatigue. Therefore, it is very important to prioritize the various requirements. It is necessary to establish the order in which each requirement needs to be fulfilled. Two important considerations are the frequency and the intensity of exposure and the possibility of integrating solutions. Defense Clothing and Textiles Agency (DCTA) in Essex, U.K. uses multiple layers of clothing, each one doing a particular function. Integrating different functions and condensing them to a minimum number of layers is a tough technological challenge. The British Army's Combat Soldier 95 system has reduced the number to eight. DCTA's goal is to reduce the number of layers to three in Crusader 21 clothing system, which is expected to replace the current outfits in 2005 (ref. 6). The integrated protection provided by the U.S. Army's battle-dress uniform is shown in Table 1.

2.3 Textiles for Protection from Nuclear Weapons

The effects of a nuclear weapon vary depending on the size, yield and type of weapon and also on the height of burst, nature of terrain, environmental conditions, etc. Due to brief duration of flash, any kind of shelter (leaves, clothing or buildings) is able to protect significantly. Flash burns are not only confined to the exposed areas of the body but also affect through varying thickness of the clothing. Even a slight increase in the thickness of clothing makes a difference between burn and no burn. Skin burns beneath tight fitting clothing but is saved in loose clothing. The first requirement of heat flash protection is to have a flame-resistant outer, which is able to reflect maximum amount of radiation back. It should be intact as long as possible to give protection from incident radiation.
**Table 1—Integrated protection offered by U. S. army's battle-dress uniform fabrics**

<table>
<thead>
<tr>
<th>Fabric Characteristics</th>
<th>Nylon, Cotton</th>
<th>Nomex®, Kevlar®, P-140</th>
<th>Cotton, Kevlar®, P-140</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flame resistance</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Liquid chemical agent resistance</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Electrostatic resistance</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Day/night camouflage</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Durability</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Weight (oz/yd²) / (g/m²)</td>
<td>7.0 / (237)</td>
<td>5.5 / (186)</td>
<td>6.5 / (220)</td>
</tr>
<tr>
<td>Cost ($/linear yd) / ($/m)</td>
<td>4.00 / (4.37)</td>
<td>20.00 / (21.87)</td>
<td>11.00 / (12.3) (estimated)</td>
</tr>
</tbody>
</table>

**Table 2—Characteristics of military ballistic fabrics**

<table>
<thead>
<tr>
<th>Property</th>
<th>Type I (Kevlar® 29)</th>
<th>Type II (Kevlar® 29)</th>
<th>Type III (Kevlar® KM2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Denier</td>
<td>1000</td>
<td>1500</td>
<td>850</td>
</tr>
<tr>
<td>Weave</td>
<td>Plain</td>
<td>2x2 basket</td>
<td>Plain</td>
</tr>
<tr>
<td>Fabric count</td>
<td>31x31</td>
<td>35x35</td>
<td>31x31</td>
</tr>
<tr>
<td>Weight (oz/yd²) / (g/m²)</td>
<td>8.3 / (281)</td>
<td>14.0 / (475)</td>
<td>6.8 / (231)</td>
</tr>
<tr>
<td>Thickness (mil) / (mm)</td>
<td>14 / (0.36)</td>
<td>25 / (0.64)</td>
<td>10 / (0.25)</td>
</tr>
</tbody>
</table>

while the portion already absorbed is transferred to the inner layers.

For nuclear protection in the U.S. army, 65/35 polyester/cotton blended fabric is used which has advantages of better durability to de-contamination process. The new fabrics usually have 1% carbon content and the rest is nylon. Nylon/polyester blends are also used in some cases. New "intumescent" substances are being investigated, which swell and char to form a thick protective layer. Even a few additional milimetres of thickness can add up to 30 s of protection.

### 2.4 Textiles for Ballistic Protection

Soldiers need to be protected from bullets and other projectiles like sharpnels, metal fragments and flying penetrating debris of various sizes, shapes and velocity. Underlying principle is of using up the kinetic energy of the projectile by dissipating it through stretching and breaking the yarns of the protective vests.

Plain or 2/2 basket weave performs the best. Loose weaves or fabrics with low yarn-to-yarn friction perform badly due to the yarn slippage at the impact point. Balanced weaves perform better than the unbalanced weaves. Ballistic protection of the eyes requires light weight transparent materials that resist ballistic penetration and are also scratch resistant.

Development in the production of high-strength polymers has been at a phenomenal rate. Presently, ballistic protection is offered by aramids, high molecular weight polyethylene and liquid-crystal based fibers; the most common of these being Kevlar®, Twaron®, Technora® (aramid) and Spectra®, Dyneema® (polyethylene). Different characteristics of the main ballistic fabrics used by the U. S. army are shown in Table 2.

A Personal Armor System for Ground Troop (PASGT) vest is made from 13 layers of Type-II Kevlar® 29 [14 oz/yd² (475 g/m²)] ballistic fabric covered by 8 oz/yd² (271 g/m²) of camouflage ballistic nylon fabric. Kevlar® also provides excellent flame and heat protection. Ballistic helmets are composites made from Kevlar® 29 (nineteen layers) and polyphenyl butyryl and phenol-formaldehyde resins. They are extremely effective and provide as good a protection as conventional steel helmet but at 15% less weight. Research is continuing to further reduce weight-to-strength ratio of ballistic protective materials.

### 2.5 Textiles for Camouflage

Earlier camouflage requirements encompassed only the visible and the near infrared regions of the spectrum. Visual camouflage is obtained by printing patterns of colors in various shades depending on the background in which it is intended for use. Detection devices now span...
ultraviolet, near and far infrared, radar and seismic sectors in an integrated multi-sensor system through visual, black and white, color, false color, foliage penetrating radars, side-ways looking radar, remote ground sensors, etc. Protection from such a wide range of possible detectors is almost impossible to attain in a single solution based on the current state-of-the-art.

The material now being used as a camouflage structure is a spun bonded nonwoven fabric to one surface of which a number of randomly oriented metal fibrils are attached. This fabric is then coated with PVC on both sides. PVC can be impregnated with specific pigments to obtain desired camouflage.

The background may not remain the same throughout an attack. Mission Research Corporation, in Santa Barbara, California, is designing an automatic camouflage system using hollow fibers filled with a mixture of liquid dye and a solid pigment. The solid pigment responds to the changing electric fields generated by a computerized camera, effecting an overall change in color of the mixture, resulting in a camouflage system that adapts to the soldier's current environment.

The U. S. army is developing camouflage fabric, called "town and country" for urban backgrounds. Another camouflage pattern which mimics the grid of a night-vision scope has been tested by the Pentagon.

2.6 Textiles for Chemical and Biological Protection

U. S. army uses permeable, semi-permeable and impermeable material systems to protect from chemical and biological warfare agents. The permeable system uses active carbon liners. These materials provide moisture vapor escape and adequate chemical agent protection. It is a nylon tricot base fabric coated with polyurethane foam impregnated with activated charcoal which provides adsorbing surface for the chemical vapor agents. Additionally, surface finishes can be applied to protect from liquid penetration. Semi-permeable systems, in the form of coatings and films, can be engineered with various levels of porosity. Microporous and ultraporous materials offer the most desirable balance of properties like high moisture vapor transmission rate, high hydrostatic resistance and chemical and biological protection. U. S. army's air crew battlefield uniform for chemical and biological protection uses a microporous semi-permeable membrane in combination with active carbon impregnated foam. The ultimate solution will consist of integration of current protective systems with selective permeable materials which will provide extensive environmental protection in addition to chemical and biological protection.

In an infested environment there is no better protection other than complete encapsulation, but it has its down-sides in that it cannot be worn for more than a couple of hours due to the problems of heat stress. It requires bulky and expensive microclimate cooling systems. Microclimate cooling vests have been developed to be used by the tank crews. A modified cooling system was used by allied forces in the Gulf war in which a centralized cooler had multiple extended vents to disperse the coolant. Soldier plugs into the system and the coolant is released inside their special vests to cool them down.

Protective gloves are usually made from butyl rubber, natural rubber, neoprene and PVA or PVC. Different thickness (7, 14 and 25 mils) / (0.18, 0.36, 0.64 mm) provide varying degrees of protection. These gloves do not provide flame retardance or POL (petroleum, oil and lubricants) resistance.

2.7 A Comfortable Soldier

The load carried by a soldier is in the range of 39-57 kg during combat conditions. This is much more than the physiologically desirable maximum of around 18.5 kg. Excessive weight impedes the mobility of a soldier and reduces his effectiveness. Everything possible is done to keep the load carried by the soldier to minimum possible. In this light even the battle dress is a candidate for weight reduction. Most NATO countries use a 305 g/m² 100% cotton fabric. In the USA, a 50/50 cotton/nylon blend [7 oz/yd² (237 g/m²) twill] is used for the battle-dress uniform. 67/33 and 65/35 polyester/cotton blends are also used in 245 and 195 g/m² constructions.

Low weight and bulk conflict with the requirements of ballistic protection, thermal
insulation, flame-resistance (application of finishes adds weight) and protection from high intensity thermal radiations.

2.8 Textiles Protect from Harsh Environment

A garment can be water-proofed by coating it with polymers such as rubber, PVC, neoprene and acrylies or polyurethanes. These solutions furnish very low permeability values (200 g/m²/24h) against the requirement of 2000-2500 g/m²/24h. Water repellant finishes are good for light showers but not adequate for prolonged exposure to heavy downpours which is not uncommon in a soldier's life. The most efficient solution is to laminate a nylon base fabric with a layer of microporous PTFE film, also known as Gore-tex membrane.

The U.S. Army Natick Research, Development and Engineering Center has developed an Extended Cold Weather Clothing System to protect soldiers from extremely cold weather. It consists of polypropylene underwear, cold weather trousers, field jacket and trouser made with a semi-permeable film laminated fabric. This system performs well up to -25°F (-31.7°C). This range can be extended to -60°F (-51.1°C) by adding a polyester pile shirt and bib overalls.

Smooth surface, achieved by using 100% man-made filament constructions of the garment is convenient for snow-shedding. Coating of silicon improves snow-shedding but has negative effects on flame-retardancy. The smooth constructions and finishes make the fabrics rustle when they are moved. Acoustic camouflage is very important since a slight noise can cost lives by attracting attention.

DCTA, U.K. is developing an "intelligent" insulation system. It is a 3-D textile in which two conventional layers are separated by a special fiber, which linearly expands or contracts with fall and rise of external temperature, resulting in regulated insulation.

3 Remarks

Obviously, a lot needs to be done to develop better protective fabrics for the military personnel. Not only in terms of performance of individual aspects of protection but also integration of solutions into a protective system, which is economical, stress-free and performs optimally. Science fiction has always found a way to become reality. Some of the threats challenging both the soldiers and the designers and scientists are as follows:

- Surveillance devices of enhanced accuracy, range and deployment methodology.
- Nuclear, chemical and biological weapons with increased lethality.
- Laser weaponry.
- Particle-beam anti-personnel weapons.
- Liquid propellant guns.
- Electromagnetic guns.
- Powerful adhesives and super lubricants for temporary immobilization.
- Less than lethal weapons.

Work is continuing towards new solutions and elimination of incompatibilities of requirements and new technologies and inventions will have a lot to offer in the future.

References