NATO Advanced Study Institute

DEFENSE RELATED INTELLIGENT TEXTILES AND CLOTHING FOR BALLISTIC AND NBC (NUCLEAR, BIOLOGICAL, CHEMICAL) PROTECTION

6-16 April 2010
Hotel Le Méridien Lav
Split, Croatia

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NATO OTAN *This activity is supported by:* The NATO **Science** for **Peace** and **Security** Programme

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Organising Committee

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This ASI on intelligent protective textiles brings together eminent researchers from all over the world to share views for the future in a well defined area.

The demand for multifunctional properties makes it necessary to develop novel textile materials with the introduction of nanotechnology, the use of a variety of sensors plus embedded electronics and special finishing treatments.

This event will result in long lasting contacts among participants from universities, research institutes and industry.

Bringing together so many people of a variety of disciplines and background from all over the world is only possible through a particular funding, i.e. the NATO funding for an Advanced Study Institute. The financial support of NATO is greatly recognised and the enabling power/capacity of such an organisation is highly welcome.

As organisers we do wish you a fruitful, enjoyable and productive ASI.

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Tuesday 6th April 2010

Session chair : Prof. L. Van Langenhove

9.30-13.00 **Opening session**

16.00-17.15 **Biodefence : how to protect the citizens**
Dr. H.A. Mayer, Abeil, France

17.45-19.00 **Methods to assess physical protection in an operational context**
Dr. W. Lotens, TNO Defence and Safety, The Netherlands

NATO ASI "Defense Related Intelligent Textiles and Clothing
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BIODEFENCE : HOW TO PROTECT THE CITIZENS

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METHODS TO ASSESS PHYSICAL PROTECTION IN AN OPERATIONAL CONTEXT

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Key Words: operational performance, protective systems, belief networks, knowledge management

1. ASSESSMENT OF EFFECTIVENESS OF PROTECTION

Physical protection is one means to protect a soldier from harm among many. The effectiveness of physical protection is rarely assessed in the perspective of alternative means because this is a difficult task. The usual approach is to specify the protection level of equipment, use it in operations and see in how many casualties this has been insufficient. Although realistic, the data usually do not reveal much of the needed background information. Few reports appear that analyse the circumstances of casualties or fatalities in terms of the parameters that help develop protective equipment.

If there are no casualties yet, protection is compared to supposed threat levels. Important political and financial decisions are made on this narrow base. In real operations there is a burden on the soldier associated with using physical protection, which changes his behaviour. And the perceived safety also changes his behaviour. Reality is thus complex, with interacting physical, operational and behavioural factors.

We can lift the scope to an even higher level by considering what the alternatives to protection are. The probably strongest factor in protection is information, allowing a soldier to avoid threats. But also the threat he can create by his own arms is a protective factor, as part of combined arms that create a wider range of appropriate effects.

In this view physical protection is a mere last resort to keep a soldier from harms way, and certainly a resort that is far from flawless and brings along severe penalties. Physical exhaustion, thermal exhaustion, lack of mobility and other hampering factors are well known counterarguments, as they deteriorate readiness. Soldiers develop a fine sense of balance between risk and burden, but different responsibilities in the military organization cause disagreement on the right balance. The perspectives of procurement, staff and user are quite different. After an incident these differences become the focus of public debate, usually with the outcome that more protection should be offered by a responsible state. Actually, also soldiers tend to accept a greater burden and train harder physically to bear the protection, until the burden wins from the relaxing risk awareness and behaviour changes. What is acceptable thus depends on who is asked and floats on the waves of risk acceptance.

Evaluation of effectiveness of protection deserves a comprehensive method in which all knowledge can be connected. Obviously, such methods cannot be deep and broad at the same time. Here we focus on a method using belief networks, which allows the analyst to collect and operationalize information from various fields to understand in a semi-quantitative way the broad picture and make the right choices before defining detailed studies.

2. USE OF BELIEF NETWORKS

Belief networks are a specific class of influence networks, based on conditional chances (for an introduction consult [1]). The method is widely used to solve a wide variety of problems, including operational problems [2]. Belief networks calculate conditional chances, depending on the input conditions. The value of the belief network is in the evaluation of input options. Selecting a certain input and toggling between input classes allows for study of the effect of that input on the overall outcome.

Belief networks are filled with beliefs, meaning that there is a relationship between connected variables, organized in parent-child relations. The variables need to form a consistent set, related to the problem, including technical, behavioural, operational and logical elements. Belief networks are easy to handle means to connect information from various sources. Whether the information comes from statistics, expert experience, model calculations, physical laws or other sources is not important, as long as the relationship between the parents and child variables can be accommodated in a table of conditional chances, called a belief.

Belief networks are crude, but fast and flexible. This means that variables may be introduced as needed to represent properties of a protective system and or of the soldier. A new insight in the desired structure of the model is quickly implemented. This allows evaluation of the addition to or removal of functions from the protective system in terms of operational performance and that is exactly the intended use. What a belief network is very good at, is showing the combined consequences of many beliefs. This complexity tends to be the weakness in human thinking.

The problem analysis and use of belief networks will be demonstrated in an interactive session, showing the type of evaluation that may be made in a helmet system analysis. The question addressed is how complex a helmet system needs to be in order to give a better trade off between protection and performance than a single helmet.

3. REFERENCES

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Wednesday 7th April 2010

Session chair : Dr. R. Rossi

9.30-10.45 **Overview of chemical biological protective clothing**
Dr. E. Wilusz, Natick Soldier RDE Center, USA

11.15-12.30 **Equipment, effectiveness & survivability of networked soldiers**
Dr. W. Lotens, TNO Defence and Safety, The Netherlands

16.00-17.15 **Smart and electronic textiles for safety and rescue**
Prof. L. Van Langenhove, Ghent University, Department of Textiles, Belgium

Work in progress on intelligent textiles for NBC protection :

17.45-18.10 **Nano and smart solutions for protective textiles**
Dipl.-Ing. Michael Glowania, RWTH Aachen University, Institut für Textiltechnik, Germany

18.10-18.35 **Communication through textiles for intelligent protective clothing**
Dr. Carla Hertleer, Ghent University, Department of Textiles, Belgium

18.35-19.00 **Research and development priorities of textiles for Finnish National Defence**
Prof. Pertti Nousiainen, Tampere University of Technology, Department of Materials Science, Finland

NATO ASI "Defense Related Intelligent Textiles and Clothing
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OVERVIEW OF CHEMICAL BIOLOGICAL PROTECTIVE CLOTHING

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1. ABSTRACT

In many aspects of everyday life it is necessary to provide protection against hazardous chemicals or biologicals. Proper protective clothing is needed during everyday household chores and home maintenance projects; in industrial, agriculture, and medical work; and during military operations and responses to terrorism incidents. This clothing generally involves a respirator or dust mask, hooded jacket and trousers or one-piece coverall, gloves, and overboots, individually, or together in an ensemble. Many different types of materials and garment designs are used in these clothing items, and protection levels vary dramatically [1]. Choices must be made as to which items of protective clothing to select for a given situation or environment. A number of variables to be considered include weight, comfort, nature of expected hazard, duration of protection required, and cost. Due to the large number of variables involved, a spectrum of CB materials and clothing systems from which to select has been developed. Fully encapsulating ensembles made from air impermeable materials with proper closures provide the highest levels of protection. These ensembles are recommended for protection in situations where exposure to the hazardous chemicals or biologicals would pose an immediate danger to life and health (IDLH).

In the military CB, protective clothing consists of an air-permeable or "breathable" two-piece ensemble fabricated from a multicomponent textile system and generally worn as an overgarment. The system can be described as having an outer shell fabric, an adsorbent layer, and an inner lining. The outer shell fabric is designed to be durable and liquid repellant. The adsorbent layer contains activated carbon or some other universal adsorbent adhered to a fabric or distributed throughout a foam matrix. The inner lining is designed to protect the adsorbent layer from abrasion against the body. This type of textile system provides very good protection against expected liquid and vapor challenges; however, despite recent improvements in comfort and weight reduction, the clothing system is still very heavy for functioning in normal operations and subjects the wearer to the possibility of heat stress under moderate workloads. Lighter weight versions of this type of clothing exist, however the level of protection is greatly reduced. If only vapor protection is required, such as might be the case for an air or vehicle crewperson, such materials can be fabricated into the form of undergarments.

Air-impermeable materials, such as elastomers and thermoplastics, are also widely used in CB protective clothing. Such materials are used in gloves, boots, and respirators. They are also used in clothing systems designed to provide protection against hazardous liquids. In general, these materials serve as barriers to these chemicals. Butyl rubber has been used for many years in gloves, boots, and some ensembles. Newer materials such as thermoplastics reinforced with fabric are now used in some of these applications but care must be taken in choosing the correct elastomeric and thermoplastic materials. Chemicals permeate through these materials by a solution-diffusion mechanism, and therefore, to maximize protection, the

solution and diffusion of the chemical must be minimized. Some ensembles are fabricated to provide primarily liquid splash protection. These suits are referred to as Occupational Safety and Health Administration (OSHA) Level B. Airtight suits provide the maximum degree of protection and are called OSHA Level A. Not surprisingly, the latter suits are the most cumbersome and also the most expensive.

The selection of the proper materials is very important in CB protective garment fabrication. However the design of the ensemble, including the selection of appropriate closure systems at the garment interfaces, is likewise important. Hazardous vapors can penetrate a CB ensemble through or around its closure systems, not just through the material itself. Careful attention must be paid to zippers, hook and loop fasteners, and drawstrings.

Over the years, methods of characterizing materials and evaluating ensembles for CB clothing have been developed and have now evolved into sophisticated methodologies. Swatch tests for materials have been developed using vapor, liquid droplet, and fully flooded liquid challenges. Methods have also been developed for evaluating full ensembles in simulated environments. In the military, the latter methods have become accepted throughout the community in recent years as an important measure of an ensemble's performance. These methods involve exposing an individual wearing the ensemble to a non-toxic simulant vapor in a chamber and measuring the amount of simulant which actually penetrates the ensemble. Similar information can be obtained utilizing an animatronic mannequin dressed in the ensemble. These latter evaluations are known as the man-in-simulant or mannequin-in-simulant tests (MIST).

2. REFERENCES

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EQUIPMENT, EFFECTIVENESS & SURVIVABILITY OF NETWORKED SOLDIERS

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Key Words: operational performance, survivability, protection, soldier behaviour, evaluation methods

1. THE MANY FACES OF PROTECTION

Networked operations are with the fielding of soldier systems reaching the very work floor of military operations. Information that was until recently not available at the lowest command level is now added to the situation awareness, increasing the capability of groups and small teams to control their situations. This has effects on both their effectiveness and their safety. In fact, where the capability to physically protect soldiers is limited, information offers ample opportunities to replace physical protection with manoeuvrability and anticipation. The C4I components of soldier systems are the enablers of information. In this vision, survivability is not synonymous with protection, but the outcome of an engagement, in which all capabilities are at stake. Because this is not different for effectiveness, effectiveness and survivability are connected and not independent goals for a military organization.

2. EVALUATING SURVIVABILITY AS AN OPERATIONAL CHALLENGE

The commonly accepted approach with five capabilities areas may be used to compute survivability. In Fig. 1 a scheme is drawn that makes transitions from left to right, from technical functions (competencies, equipment, human factors, doctrine, etc.) into tactical capabilities (as used in armed engagements) and further to the operational level, evaluating the success of the mission. A framework of measures of performance is associated with the concepts in the scheme. Of course, the scheme is a simplified version of the reality. The skill of the investigator is to expand and limit the scheme in a way that fits the problem he is investigating. There is thus not a single scheme, but as many as there are investigations. The scheme explains why survivability depends on manoeuvrability, lethality and sustainability and why C4I is founding situation awareness and consequently manoeuvrability. The relevant military outcome is the operational success, but this may come with a price: own casualties, civil and opponent casualties, damage, consumed resources, loss of readiness, time passed etc. The importance of the cost factors may depend on the need for the unit for further actions, thus depends on the higher aims.

This approach may relatively easy be implemented in Bayesian belief networks. The more exact approach would be combat simulation. Unfortunately no simulation package is currently comprehensive enough to handle all the influences involved.

What we can do with this approach is to compare effect on operational success and cost factors of various technical enhancements. To decrease the casualty rate, unequal measures may be made comparable, such as introduction of better body armour, better vision aids, UAV mounted IR cameras, GPS localization or training for higher soldiering. This really advances the optimization of the system.

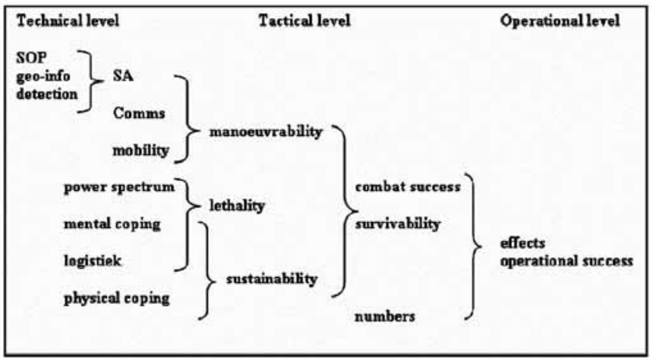

Figure 1. Scheme showing that the usual capability areas are not independent, but rather feed into each other, with survivability as an outcome. This perspective on survivability takes into account all alternatives to physical protection.

3. THE WEIGHT CASE

As a suitable case we will study the effect of extending ballistic protection. Providing higher protection has a weight penalty, which will affect both the mobility and the exhaustion level. On the other hand, soldiers will feel safer and change their risk taking behaviour. It has been observed that risk taking tends to stabilize at a certain perceived risk level, which results in more risky behaviour by those who feel better protected (risk homeostasis). The more risky behaviour may result in a military advantage, for instance higher momentum. Without further analysis nobody can be certain that introducing heavier body armour will decrease casualty rates. During the session, we will study this weight case as it is an interesting model for other protective measures.

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SMART AND ELECTRONIC TEXTILES FOR SAFETY AND RESCUE

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Key Words: smart textiles, protection, monitoring, communication, textile integration.

1. INTRODUCTION

Smart or intelligent textiles are a new generation of textiles that will actively contribute to our health and safety.

They are expected to be one of the roads to a new sustainable textile industry. They are high tech products with a high added value, knowledge based, highly specialised and addressing specific target groups.

Smart textile products are stand alone systems that are able to monitor and react. The sensors provide information on the person or the environment. The smart suit contains an electronic box and energy supply. The smart textile system provides an adequate reaction enabling fast response and even prevention.

2. WHY TEXTILES?

Clothes are our own personal house. They can be made to measure, with a perfect fit and high level of comfort. Clothes make contact with a considerable part of the body. They are a common material to all of us, in nearly all of our activities. They look nice and attractive, the design and look being adapted to the actual consumer group. We all know how to use them. Maintaining textile is a daily practice: domestic as well as industrial laundry are well developed.

Textile structures are extremely versatile in terms of products as well as processes. The building stones of the textile material (*fibres* or *filaments*) are made of a broad range of materials, pure or in combinations. Smart configurations and combinations of materials, advanced treatments and technologies allow to achieve very special properties such as hydrophilic/hydrophobic nature, antimicrobial, selective permeability etc.. Textile materials are able to combine advanced multifunctionality with traditional textile properties.
And last but not least: textiles and clothes can be produced on fast and productive machinery at reasonable cost.

All this makes smart clothes an ideal vehicle for carrying active elements that permanently monitor our body and the environment, providing adequate reaction should something happen.

3. APPLICATIONS OF SMART TEXTILES

2.1 General

Smart textile products monitor man and his environment. Many body parameters can provide useful information on the health status of a person: temperature, biopotentials, sounds, movements, chemicals, mechanical parameters and many more. Several research projects are being undertaken for measuring body parameters using textile as a carrier of sensor systems or the textile itself as sensor [1, 2, 3, 4]. Such suits commonly measure heart rate, temperature, respiration and gesture. Permanent monitoring combined with smart data processing strategies allows early detection of suspect conditions.

Protection is the second frame: the textile can react adequately on hazardous conditions that may have been detected. The reaction can consist of warning, prevention or active protection. After an event has happened, the smart textile is able to analyse the situation and to provide first aid.

On a longer term the textile can support and follow up the healing process. Support to rehabilitation can be medical or chemical or physical. Textile materials can contribute to enhancing the rehabilitation process; they can actively support body deficiency or even take over certain functions.

2.2 Specific applications for the military sector

The paper will give an overview of current technologies and developments that can be applicable for the military sector.

4. REFERENCES

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NANO AND SMART SOLUTIONS FOR PROTECTIVE TEXTILES

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Key Words: textile reinforced thermoplastics, impact strength, ballistic protection, fire fighters, sensor

1. INTRODUCTION

The Institut für Textiltechnik der RWTH Aachen (ITA) presents two public funded projects. The first one is called NanoOrgano and is funded by the Federal German Ministry of Education and Research. ITA and partners investigate a new technology for the production of drapable nanomodified thermoplastic preforms to achieve a higher impact strength.
The second project is called ProFiTex and is funded by the European Union. The aim of the project is to support fire fighters in their perilous work with a system that supplies mission-relevant information without overwhelming the fire fighters.

2. NANOORGANO

Textile reinforced thermoplastics are composite materials, that become more and more important also for ballistic protections. For their production, mainly pre-consolidated stiff preforms are used. In a following step, these thermoplastic "prepregs" are heated up and molded to structural parts. However, this two-step-process is time- and cost-consuming [1]. Hence there is a high demand for a cost-saving technology that allows the production of thermoplastic composites with enhanced mechanical properties in a single process step.
In collaboration with research institutes and industrial companies, a new technology for the cost-efficient production of composite parts with improved mechanical properties is being investigated (Figure 1).

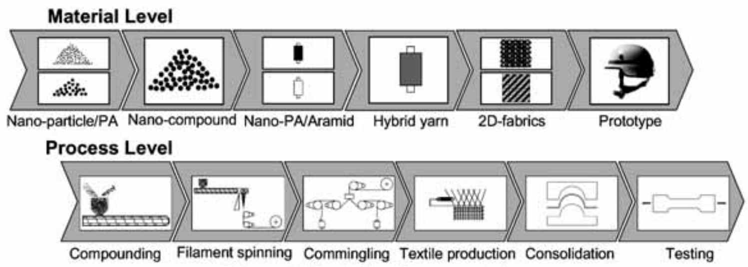

Figure 1. Material- and process-chain

Innovative drapable thermoplastic preforms are being developed. In order to improve the mechanical properties of the composite, a modification of the thermoplastic component with nanoparticles is made. Within the research project "NanoOrgano", different types of nanoparticles are used, together with polyamide (PA), for the production of nanocompounds. These are further processed to continuous filament yarns. In a following process step the nanomodified PA filaments and different types of Aramid yarns are commingled to hybrid yarn structures. The commingled yarns are further processed to drapable thermoplastic "prepregs" in form of woven and multi-axial warp-knitted fabrics. In order to investigate the mechanical properties of the new nanocomposites, the different textile structures are consolidated and moulded in a one-step-process to a high-performance helmet, which is further used for investigation of the mechanical properties. [2]

3. PROFITEX

Fire fighters can be equipped with information and navigation systems that support them in their perilous work. The top priority is not to overwhelm the fire fighters with information but rather select only mission-relevant parameters. In the project ProFiTex professional fire fighters are involved from the beginning of the project to ensure that the system tailors to their needs. A fire fighting jacket with integrated sensors and electronics as well as a braided security rope which is able to transport data are the main components of the system (Figure 2). The jacket comprises electronic devices like an infrared camera, movement and localisation sensors and a human-computer interface device integrated into the jacket sleeve. Wire-bound data transfer is used since wireless communication is difficult over long distances and through several walls of a building. A newly developed security rope allows information to be sent outside to the command post and back to the fire fighter. Several parameters of the fire fighters' condition like his movement pattern and stance are monitored to detect problems immediately.

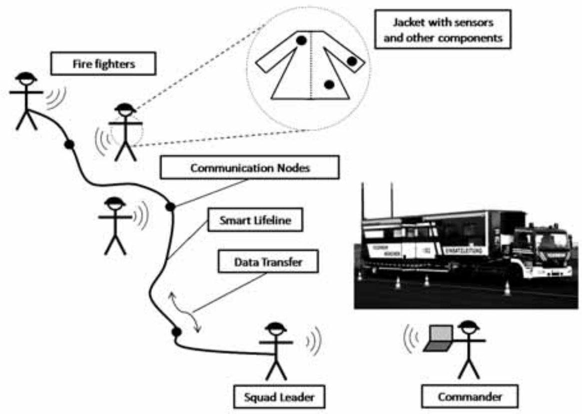

Figure 2. ProFiTex - Project outline

Information will be displayed to the fire fighters, their group leaders and the commander outside the building. The amount and type of information supplied will be carefully chosen, considering the physical danger and psychic stress fire fighters are opposed to.

4. REFERENCES

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COMMUNICATION THROUGH TEXTILES FOR INTELLIGENT PROTECTIVE CLOTHING

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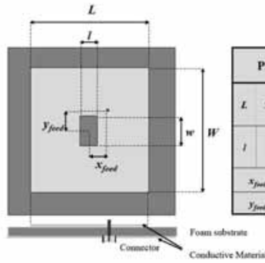
Key Words: textile antennas, off-body communication, wireless data transmission, e-textiles

1. INTRODUCTION

With the introduction of intelligent textile systems, the functionality of personal protective clothing is further enhanced. High tech fabrics protect the wearer from harsh environmental conditions, while monitoring systems provide information about his physical state during operation. A wireless communication device between the wearable system and an external base station is required. In this work, a protective foam-based antenna for integration into intelligent protective clothing is developed.

2. ANTENNA SPECIFICATIONS AND DESIGN

The antenna is designed to operate in the 2.45 GHz ISM (Industrial, Scientific, Medical) band where a bandwidth of at least 83.5 MHz is to be obtained. Furthermore, the antenna has to radiate 90% of the incoming power in this frequency range. The rectangular ring topology has proven to be suitable [1]. As antenna substrate material, flexible pad foam was selected because it is commonly available in protective clothing and it does not hinder the wearer in his movements. This foam is 5.5 mm thick. All details of the antenna dimensions and characteristics are given in Figure 3.



Patch (mm)				Substrate	
L	52	W	48	h (mm)	5.55
l	9	w	15	ε_r	1.12
x_{feed}		12		$\tan\delta$	0.003
y_{feed}		8			

Figure 3. Topology and characteristics of the antenna

On the backside of the antenna, a ground plane is placed in order to prevent radiation towards the body. Antenna patch and ground plane our manufactured out of e-textiles, which are electrically conductive fabrics.

To improve overall flexibility, the antenna is fed with a coax cable that is attached with conductive glue to the antenna patch and to the ground plane.

3. ANTENNA PERFORMANCE

Figure 4 shows that the design criterion of reaching a return loss of less than -10 dB (90% radiation) in the entire ISM band is largely fulfilled. Moreover, a bandwidth of over 280 MHz is achieved. This contributes to the robustness of the antenna since it becomes less vulnerable to frequency shifts due to e.g. manufacturing inaccuracies or bending.
In a transmission measurement set-up, the textile antenna is applied as receiving antenna with a standard gain horn as transmitting antenna. An antenna gain of 6.7 dBi was found, which guarantees a good communication link during real-life operation.

When designing an antenna to be applied in a protective garment, sensitivity to humidity has to be taken into account. To do so, a foam material with a very low moisture regain of 0.84% was chosen. To examine the influence of humidity changes, the antenna was conditioned in a climatic test cabinet for 24 hours in a temperature of 23°C and a relative humidity of 30, 50, 70 and 90% respectively. Fig. 3 shows that for this kind of material the frequency shift is only limited, especially when compared to natural fibre based materials that have a much higher moisture regain (up to 8%) as analysed in [2].

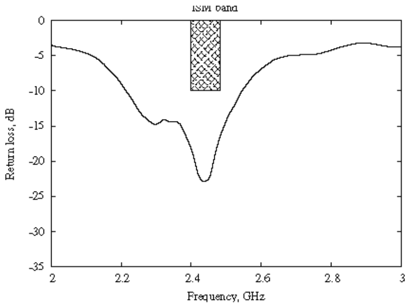


Figure 4. The entire 2.45 GHz ISM band is covered

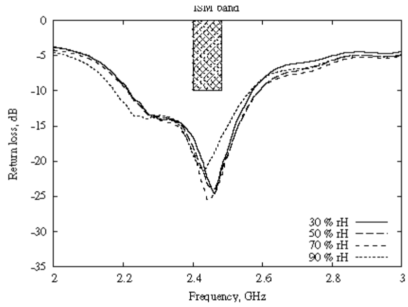


Figure 5. Changing environmental humidity only slightly influences the return loss

4. CONCLUSIONS

A flexible pad foam material is applied to design and manufacture a robust antenna for integration into intelligent protective clothing. The proposed antenna has a sufficiently large bandwidth of 280 MHz and a high gain of 6.7 dBi to establish a good off-body communication link. Given the small moisture regain of the foam material (0.84%), the antenna provides a stable return loss characteristic in changing environmental conditions.

5. REFERENCES

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NATO ASI "Defense Related Intelligent Textiles and Clothing
for Ballistic and NBC (Nuclear, Biological, Chemical) Protection

RESEARCH AND DEVELOPMENT PRIORITIES OF TEXTILES FOR FINNISH NATIONAL DEFENCE

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Key Words: defence science, materials, fibres, textiles, military clothing

1. INTRODUCTION

The multiple structures active on European security and cooperation in national defence and crisis management is increasing the need of cooperation of research institutions and universities. Organizations, such as Western European Union (WEU) and NATO have promoted the cooperation between members and non-members e.g. by partnership for peace (PfP), Euro Atlantic Partnership Council (EAPC) and Partnership for Production (PARP). Several technical research topics can be handled in defence material managers conferences and working groups, such as production, application, storage and standards.
Nordic cooperation on military technology traditionally relate to the change of warfare experiences, adoption of climatic conditions, conferences programs and production/sourcing capabilities. The discussion on the change of security threats from global to local conflicts and environmental risks has been carried out. The main target has been to ensure the key functions of the society taking into account the complex inter-dependence of functions. New challenges deal with the need for quick operations in different levels and possible psychological attacks, as well.

2. DEFENCE MATERIALS

Defence materials of the 21st century needed for district defence systems and readiness brigades of different levels of armed forces are divided into high tech and normal outfits. The modernisation of materials under a decreasing budget includes basic purchase of weapons for land forces and combat fighters in the 90´s. Purchase programs include mobile artillery, rockets, missiles, helicopters, Hornet fighter´s supplements, passive sensors and flying fighter robots. Equipments for information technology for real-time management increasingly include sensors and micro-processors "for every soldier". Those are planned for smaller, efficient, flexible, reactive, highly mobile forces with new capabilities against new threats.

3. WARFARE TECHNOLOGY AND THE NEED FOR SCIENTIFIC APPROACH

Warfare technology is characterized by increased mobility, precise destruction, robots, rapid e-information and simulation for decision making. For combat soldiers this means improved protection, maintenance, module systems of clothing and personal equipments, e-warfare devices, reconnaissance technology, fire control/new cartridges, sensor signal processing, and shielding/ELSO systems."The footsoldier will remain central to warfare", expressed by Heisbourg means that the fighter´s personal combat equipment and clothing is important especially in conditions in Nordic countries. Textiles and composites are useful in camouflage, in ballistic and bullet vests, tents, shelters, protectors and to carry sensors for detection [1].

R&D for Finnish National Defence is carrying out activities for simulation of threats, modelling of battles based on the demands of the end-users. It has a long tradition of cooperation with the industry and research institutions. Projects focus on critical technologies, such as reconnaissance, shield-camouflage, logistics, radar, e-optics, radio-sensors, data protection, ELSO, standards and medical care. The main scientific work is carried out by the Scientific Advisory Board for Defence (SABD) consisting of a network of 22 units for R&D resources and Universities, VTT and industry. SABD is divided into 7 science sectors including computers, electronics, technical, natural, administrative, behaviour, and medical sciences. There are 11 active expert sections and 3 local sections [2].

4. SCIENTIFIC ADVISORY BOARD FOR DEFENCE

The Texile and Clothing Section's (TCS) main focus is: clothing physiology, fibrous materials, technical textiles. The respective main research areas include: soldier´s combat clothing (M2005-M2020), soldiers in extreme thermal conditions, advanced materials and clothing accessories, ballistic protection materials and solutions, camouflage and EMI/IR/Radar protection and (N)BC protection and durability. Numerous reports and publications have been produced by TCS up to year 2008, such as

- The development of camouflage against heat flux
- The measurement of pumping effect on protective clothing against cold
- Development of low –friction garments
- Special footwear for assault operations
- Military footwear in cold conditions
- Comparison of different materials for ABC-clothing
- Footwear development, face protection against cold
- active: development of new light weight personal ballistic protection
- active: development of new composite structures for ballistic protection
- NATO PfP Exhibitions: Combat clothing and personal equipments
- PASS and ISSS participation 2005 [3].

According to the future strategy of SABD/TCS the target is response to the research needs for sustaining the key functions of society by utilizing the multidisciplinary approach. The cooperation with additional partners outside MoD, especially within EU countries is aimed at, and SABD aims to stay a highly recognised organization of experts. TCS is active on scientific research of materials and applications of fibres and textiles for clothing, textiles and composites.

The special objective is to increase the efficiency of a combat soldier by means of protection and functionality of materials. The focus areas are: advanced materials, soldiers in exceptional thermal conditions, ballistic protection camouflage technology and sensor applications.

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Thursday 8th April 2010

Session chair : Prof. P. Noussiainen

9.30-10.45 **Fiber sensors for personal protection**
Prof. A. Lobnik, University of Maribor, Slovenia

11.15-12.30 **Activated natural zeolites on textiles - ability to protect from radioactive contamination**
Prof. A.M. Grancaric, University of Zagreb, Faculty of Textile Technology, Croatia

16.00-17.15 **Electromagnetic radiation and intelligent textiles for protection and security**
Prof. I. Prlic, Institute for Medical Research and Occupational Health, Croatia

17.45-19.00 **Experimental workshop on electromagnetic fields**
Prof. I. Prlic, Institute for Medical Research and Occupational Health, Croatia

NATO ASI "Defense Related Intelligent Textiles and Clothing
for Ballistic and NBC (Nuclear, Biological, Chemical) Protection

FIBER SENSORS FOR PERSONAL PROTECTION

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Key Words: optical sensors, fibers, personal protection

1. INTRODUCTION

With regard to the Sustainable Chemistry Strategic Research Agenda 2005 (SusChem), looking forward to 2025, a new paradigm is required to provide optimal and personalized human care as a result of the increase in life expectancy and the aging population. Sensor technology provides a connection between a biological function and an electrical signal. Advanced sensors and new micro-analytical devices will have a substantial impact on health, environment and individual protection strategies in the coming years. Furthermore, functional textiles that recognize and destroy toxic agents based on new sensor systems will play an important role as components of security systems.

Fiber-optic chemical sensors (FOCSs) represent a subclass of chemical sensors in which an optical fiber is commonly employed to transmit the electromagnetic radiation to and from a sensing region that is in direct contact with the sample. In addition to advantages in terms of cheapness, ease of miniaturization, obtaining safe, small, lightweight, compact and inexpensive sensing systems [1], they can also be embedded into textile structures [2].

The most common classification of FOCs distinguishes between intrinsic and extrinsic types of sensors [3].

- In FOCs of the intrinsic type, the sensing principle is based on the change in light-transmission characteristics due to the change occurred in a fiber property (e.g. refractive index or length) upon the interaction with the analyte or the system being studied. The optical fiber itself has sensory characteristics. This type of sensor is mainly applied to measure physical or physicochemical parameters, such as pressure, temperature, or enthalpy of reactions.

- In FOCs of the extrinsic type, the optical fiber acts as a transporting media by means of guiding the radiation from the source to the sample or from the sample to the detection system. Extrinsic sensors can be subdivided into a) distal and b) lateral types. The most common are distal-type sensors, in which the indicator is immobilized at the distal end (tip) of the optical fiber. Alternatively, in lateral sensors, the sensing chemistry can be immobilized along a section of the core of the optical fiber to make an evanescent field sensor.

An optical fiber is a cylindrical cable whose diameter can range from less than one µm to several hundred mm. The materials most commonly used in the fabrication of the fibers are plastics, glasses, and quartz. Because of transparency reasons only glass optical fibers (GOF) or polymer optical fibers (POF) can be used in fiber optics. Although the transparency of glass is superior to that of polymer, in the majority of cases, POF are used since the production costs are lower, they are more flexible and the immobilization of the indicator is easier. Moreover, for the integration of the FOCSs in the textile structures, POFs are more useful since they are more resistant to textile manufacturing processes and have a higher safety potential, compared to glass fibers [4]. FOCS are receiving more and more attention in the field of smart textiles.

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NATO ASI "Defense Related Intelligent Textiles and Clothing
for Ballistic and NBC (Nuclear, Biological, Chemical) Protection

ACTIVATED NATURAL ZEOLITES ON TEXTILES - ABILITY TO PROTECT FROM RADIOACTIVE CONTAMINATION

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Key Words: *natural zeolite, cotton fabric, natural radioactivity, radioactive contamination.*

1. INTRODUCTION

The scope of the specific experimental research was to investigate the behaviour of given textile samples processed with *clinoptilolite* zeolite regarding the radioactivity - radioactive contamination in order to be able to classify the processed textiles into the group of possibly radio protective materials (personal and/or industrial textiles containing natural and/or artificial zeolites). The civil need for such textiles is obvious in the quickly growing field of nuclear medicine and PET/SPECT isotope production. Quantitative health risks for the persons wearing clothes made from the new fibres and impact on their health is to be evaluated for each situation, military and security purposes and for civil use [1].

Since natural zeolite clinoptilolite has a crystalline configuration and a lattice structure with long channels comprising water molecules and alkaline earth ions, these ions may shift within the lattice, enabling clinoptilolite to have strong absorbency, even for heavy metals and toxins, and ion exchange properties [2]. In this paper, cesium (Cs) is considered to be in the first place of zeolite ion-exchanging selectivity, as follows [3]:

$Cs > NH_4^+ > Pb^{2+} > K^+ > Na^+ > Mg^{2+} > Ba^{2+} > Cu^{2+} > Zn^{2+}$

Applications on textiles are following the tendency for new textile applications as materials for human performance, such as medical, protective and sports [4]. As a physical property of zeolites is their ability of adsorption, it is clear that the use of textiles processed with zeolites will be physically predisposed to be used in the field of radiation protection where the liquid radioactive contamination is expected. Other physical properties (capture of free atomic dust particles) are not possible or are too slow to take place when talking about radioactivity and practical radiation protection. It is clear that zeolites can be used to hinder the radioactive alpha and beta contamination but the gamma (electromagnetic) component of ionizing radiation passing through textiles processed simply with natural zeolites can't be prevented. However, the zeolites can adsorb certain amounts of contaminated liquid.

2. MATERIAL AND METHODS

The basic experiment validating the necessary input parameters for further research regarding radiation contamination prevention using zeolite processed textiles was conducted. A circular weft single jersey of 100% cotton, mass per surface area of 123 g/m^2 was used. It was mercerized with 24% NaOH without **(BM)** and with **(BZM)** addition of 10 g/l of natural zeolite nanoparticles **(Z)**. Applied nanoparticles that consist of 80% clinoptilolite and 20% montmorillonite and mordenite, were activated and made by tribomechanical activation [3].

The Naturally Occurring Radioactive Material (NORM) radioactivity concentration of these samples was determined by means of gamma-spectrometric analysis in the laboratory using HPGe and/or Ge(Li) detector (resolution 1.78 keV on 1.33 MeV ^{60}Co, relative efficiency 16,8%; resolution 1.56 keV on 1.33 MeV ^{60}Co, relative efficiency 18,7%).

3. RESULTS & DISCUSSION

All radionuclides listed in Table 1, except anthropogenic ^{137}Cs are naturally occurring. The activity concentration of naturally occurring radionuclides indicates that both natural zeolite mineral and cotton fabrics are natural materials. It can be assumed that a high content of radioactivity in cotton fabrics originates from an artificial phosphor fertilizer (the ^{40}K is very high then and Cs is very likely to be found as well because it replaces the K in chemical bounds then of the food growth chain) [5].

Table 1. The gamma-spectrometric analysis of zeolite and cotton samples

Radio nuclides	Activity concentration [Bq/kg]								
	Z			BM			BZM		
^{238}U	125,82	±	32,32	13,86	±	5,52	35,33	±	10,04
^{232}Th	45,55	±	2,64	9,76	±	2,45	12,41	±	4,10
^{235}U	< 4,99	±	0,27	0,69	±	0,52	< 1,27	±	0,32
^{226}Ra	50,91	±	3,87	35,73	±	6,89	35,13	±	6,45
^{228}Ra	45,55	±	2,64	9,76	±	2,45	12,41	±	4,10
^{210}Pb	45,12	±	2,58	16,24	±	4,43	8,74	±	3,29
^{241}Am	1,22	±	0,32	3,49	±	0,52	2,82	±	0,36
^{40}K	938,53	±	7,80	172,07	±	10,40	150,96	±	11,19
K / gkg^{-1}	30,47	±	0,25	5,59	±	0,34	4,90	±	0,36
^{137}Cs	0,69	±	0,18	1,28	±	0,50	1,57	±	0,32
^{7}Be				5,02	±	3,50			

4. CONCLUSION

The presence of the fission product ^{137}Cs in the natural zeolite and cotton fabric could be traced to the fallouts occasioned by the various nuclear tests all over the world, and probably, some effect of the more recent nuclear reactor accident at Chernobyl in 1986 [6]. From the point of view of "contamination", the samples were clean. Any artificial radioactive contamination to which the samples could be exposed and any adsorption process fixing the contamination into the zeolite compound can be measured after the textile will be used for contamination cleaning (decontamination) of preferably liquid radionuclide contamination. In the nuclear medicine the contamination of a working area (hot spot where the radionuclide dosage for diagnostic or therapeutic purposes is determined) is highly possible. The radionuclides are liquid mixtures, applicable with a needle into the patient. This is a possible working environment where the zeolite textiles can be applied (for "sucking" the contamination) [7].

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ELECTROMAGNETIC RADIATION AND INTELLIGENT TEXTILE FOR PROTECTION AND SECURITY

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Key Words: EM radiation, radiation protection, homeland security, interaction with matter, occupational health, intelligent textiles

1. INTRODUCTION

EM radiation is partly not natural to humans. Some frequencies are not reaching the Earth surface at all (Fig. 1.) [1]. Life was developed in the absence of denoted EM energies. New telecommunication technologies (Radar, GSM, UMTS, WiFi, ...) are based on the non natural frequency ranges of the EM spectrum (Fig 1.). Therefore, it is justified to research the impact of these frequencies on the humans' life and biota. The EU has adopted the new moral and political concept based on the precautionary principle [2] while introducing the new technologies into daily life, first to ensure a healthy environment and biodiversity and secondly, to ensure the minimum risk to humans while using the new, possibly hazardous, technologies. Today, the urgent need to enhance the security of a civil daily life broadens the boundaries of radiation usage. Radiation protection procedures introduce various protective tools and clothing, intelligent protective textiles, which can assure the minimum risk and socio economical benefit to society while developing new working places using the EM radiation. Through that process the development of new textile formats capable to protect humans from non natural external EM radiation is a scientific and professional challenge.

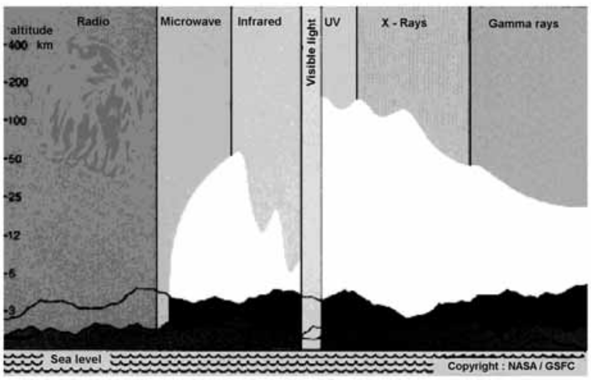

Figure 1. The transparency of the Earth's atmosphere: Electromagnetic radiation (nonionizing and ionizing) from space is unable to reach the surface of the Earth except at a very few wavelengths, such as the visible spectrum and radio frequencies (NASA/GSFC)

1.1. Defense related intelligent textiles

Many of the innovations in textile applications in the past 50 years have started with military applications - from fiberglass structures, to fragment and bullet resistant body armor, from chemical protective clothing to fibre-reinforced composites. Although the protection from, in nature, non existing energies is not really the defense related must; the development of defense related intelligent textiles and clothing is to be regarded as a natural human effort of protecting the species from potentially hazardous man made agents – stressors. New technologies used to enhance civil security developed in the last few decades are mainly oriented towards the early warning of possible terrorists threats (radiological, chemical, biological, …) and can cause harm to human health if not properly used. A good example of this statement is introducing the T-body [3] scanner at airports to meet the homeland security standards. Defense related equipment – MIL standard – producing EM fields is used to define and bring to life and into the operation the modern network soldier concept – clusters of well defined combat activities carried out by a minimal number of well trained and exceptionally well equipped [4] soldiers. The must for this combat option is a uniform, well defined clothing made to protect the soldier in person (his physiological and functional health) and to protect the sensitive networking telecommunication systems.

1.2. Medical and civil related intelligent textiles

Engineered and smart textiles are made possible due to advances in many technologies coupled with the advances in textile materials and structures. A partial list includes biotechnology, nanotechnology, information and telecommunication technology, micro-electronics, wearable computers and micro-electromechanical machines.
There are, of course, many more applications for engineered and smart textiles than those applied to military personnel. Mountain climbers, sportsmen, business people with built-in wearable computers and medical personnel, all benefit from this revolution of textiles.
All above enumerated technologies are using EM to be powered or for wireless transport of various necessary data.

1.3. Inevitable physics of EM interaction with textiles

No matter which type of production (weaved, knitted or else), or which type of raw material mixture is used, a simple basic (Maxwell's) EM law is conducting the final intelligent attribute of the final textile product:

$$\nabla\vec{B} = 0 \tag{1}$$

meaning that no magnetic monopolies exist and the magnetic flux is always closing itself into itself (solenoid behavior of magnetic dipoles). Practically, it means that no protective barrier is possible to prevent the hostile magnetic flux from penetrating into any volume of interest, meaning that if a soldiers body is a volume of interest, no clothing (uniform) no matter how "intelligent" it is, will prevent the outdoor magnetic flux from a hostile source to flow through the soldiers body. This fact is the basic one when discussing the intelligent textiles used for military uniforms to ensure the integrity of a network soldier disposed to a hostile magnetic flux. The same law will affect any intelligent textile used for medical purposes. Therefore, the intelligent textiles, used to enable the information and telecommunication technology to be used, are regarded to be fully protective if they cannot be affected by means of an EM hostile flux.

Only an Earth made magnetic flux is present at all times and no magnetic flux emitting weapons were developed because the war doctrine was to destroy and kill the enemy. A future doctrine, especially a network soldier concept, is becoming actuality with a different view of "destroying" thingy or human force. The soldier is to be reused. In that sense the enemy soldier (or terrorist) activity is to be destroyed. This means that the telecommunication with the base and all other computer soldier activities must be blocked. The EM magnetic flux is the best way to do so.

Intelligent textiles for a civil use, based on telecommunication, nanotechnology and with biodegradation ability, can play a crucial role in human protection from various, specially man made hostile or accidental situations (crude oil dwelling industry, mining, chemicals, underground and underwater constructing etc.).

2. PRESENT STATUS

There is no ongoing defense related research based on the protection from EM fields in Croatia. The production of military textiles uses well known procedures to impregnate the uniforms to be UV protective. Research partly performed in the last decade was the research of possible interaction of high frequency EM fields, used for mobile telecommunications, with human tissue. Occupationally exposed workers working at the mobile phone base stations (high masts and the HF antennas) are exposed to various amounts of very fast time varying EM fields – Near field region – from base station antennas. There is no protective clothing recommended for them. The precautionary principle is used (antennas are shut down while they are working in the vicinity of them). This is questionable. We have used the spectrum analyzer (Anritzu®) system with a set of HF antennas and power meters to measure a great number of points exposed to HF telecommunication EM fields. We were measuring in far field conditions in order to collect the relevant data corresponding to as many as possible homogenous exposures achieved in laboratory conditions using TEM chamber arrangement [5]. Measuring the E or H values in the near EM field of the antennas is possible, but the results are not plausible. Only the data about the average irradiated power from the antennas, taking into account a high measuring uncertainty factor, can be considered. But nevertheless, the measured power data opened a discussion whether the people working in the near EM field of telecommunication base stations and radar systems [6] are to be protected against the EM radiation and when yes, how. The development of suitable working clothing came up the table. This immediately raised questions about the interaction of HF with the human tissue if the electrical equipment is integrated into the clothes – military uniforms (fig 2.) or special protective clothing (fire brigade or police). Modern clothing can be merged with GPS tracking systems, life detecting electronic sensors, computing systems (nano fiber) USB connectors and power supplies, optical fibers etc..

The new technologies opened a broad field of enhancing any textile with some metal material (preferably nanotechnologies) ensuring the versatile usage of the textile producing the self sustainable power for all the electronics integrated. The research of EM fields is important because of the fact that most of the modern man made technologies are based upon the use of EM which is NOT natural to humans, but which at the moment are enabling the humans a very leisurely life. Sometimes the protecting from EM just to protect will (or can) cause more harm than not protecting at all.

Therefore, it is recommended to redefine the wording "protective textiles" when talking about the protection against the EM fields, because we have to define first from which EM fields and field potency are we protecting ourselves and why are we doing it: to protect our health or to protect our activity? Intelligent textiles can cover both issues. Comprehensive discussion covering the issue is to be continued during the NATO ASI in Split 2010.

Figure 2. A network soldier – electronically equipped – full 3D computer guided (face blurred)

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Friday 9th April 2010

Session chair : Dr. E. Wilusz

9.30-10.45 **The engineering design of intelligent protective textiles and clothing**
Prof. S. Jayaraman, Georgia Institute of Technology, USA

11.15-12.30 **Modelling of ballistic impact on fiber composites**
Dr. H. van der Werff, DSM Dyneema, The Netherlands

16.00-17.15 **Nuclear threats, physiological effects, and countermeasures**
Dr. R. DeMeo, Radiation Shield Technologies, USA

17.45-19.00 **Developments in decontamination of military soldiers and equipment using fibrous materials**
Prof. S.S. Ramkumar, Texas Tech University, USA

THE ENGINEERING DESIGN OF INTELLIGENT PROTECTIVE TEXTILES AND CLOTHING

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Key Words: Engineering design framework, protection, comfort, materials, manufacturing technologies

ABSTRACT

Textiles and clothing are pervasive. Unfortunately, terrorist threats are increasingly on the rise be they nuclear, biological, chemical or ballistic in nature. Therefore, protection against such threats is of paramount importance for preserving peace and security around the world, especially for ensuring the safety of defense personnel engaged in confronting and responding to such threats. The design of textiles and clothing for protection against such threats presents an interesting set of challenges and opportunities for the engineering design of such structures.

In this paper, we present an engineering design framework for the design and development of intelligent protective textile structures and clothing. We begin with an analysis of the various types of threats against which individuals must be protected. Using this taxonomy of threats, we develop a set of performance requirements – ranging from protection against the various threats to the comfort of the active user – for such textiles and clothing. We then discuss the translation of these requirements into the realization of structures through the optimal selection of materials and manufacturing technologies. We conclude the paper with an analysis of the opportunities and challenges for intelligent textiles and clothing whose ultimate objective is the realization of cost-effective protection and safety *anytime*, *anywhere* for *anyone*.

NATO ASI "Defense Related Intelligent Textiles and Clothing
for Ballistic and NBC (Nuclear, Biological, Chemical) Protection

MODELLING OF BALLISTIC IMPACT ON FIBER COMPOSITES

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Key Words: Dyneema, ballistic impact, numerical modelling.

1. INTRODUCTION

High performance polymeric fibers play an important role in light-weight armor materials used to protect personnel either through armor worn on the body (vests, inserts, helmets) or through armor attached to the interior of personnel transport vehicles used in air, on land or water. It is the intention of this paper to identify the essential fiber and geometric properties that largely determine the ballistic performance of fiber based composite targets. Knowledge of these relations is necessary to find new opportunities for improved armor materials.

2. RELATION BETWEEN FIBER PROPERTIES AND BALLISTIC PERFORMANCE

A broad overview on this subject has been given by Phoenix and Porwal [1]. Empirically, it had already been reported by Cunniff [2] that, through dimensionless analysis, a single curve could be used to relate normalized experimental V50 values of a wide variety of fiber based armor systems impacted by standardized steel right circular cylinder (RCC) projectiles to the system areal density ratio. The dimensionless fiber quantity of relevance was found to be the product of fiber specific toughness (*i.e.* elastic energy to break in a tension test per kg of material) and the velocity of sound in the fiber, to be denoted here by Ω (having units m^3/s^3):

$$\Omega = \frac{\sigma \cdot \varepsilon}{2 \cdot \rho} \sqrt{\frac{E}{\rho}} \tag{1}$$

where σ is the fiber strength (N/m^2), ε the elongation at break of a fiber, ρ the fiber density (kg/m^3) and E the fiber modulus. Basically, the following relation was found by Cunniff [2]:

$$\frac{V_{50}}{\sqrt[3]{\Omega}} = f\left(\frac{AD_{\text{target}}}{AD_{\text{projectile}}}\right) \tag{2}$$

where AD is areal density, and $f(\cdot)$ is the empirically determined functional relationship, i.e., master curve, from experiments on a wide variety of material systems.

A similar relation was theoretically derived by Phoenix and Porwal [1] for an initially untensioned, infinite, in-plane isotropic target membrane with a certain density, thickness and Young's modulus, impacted with a projectile with a certain radius and areal density However, these authors were also able to derive the functional form of the relation, showing excellent agreement with Cunniff's master curve.

Rearrangement of eq. (1) using textile based units for strength (cN/dtex) and modulus (N/tex) gives the following result for the cube-root of Ω, which is then linearly related theoretically, via the function *f*, to the V_{50} of any combination of a fiber based composite target and an RCC projectile:

$$\sqrt[3]{\Omega}\ (\mathrm{m/s}) = 171\frac{\sigma(\mathrm{cN/dtex})^{2/3}}{E(\mathrm{N/tex})^{1/6}} \tag{3}$$

The basic conclusion of eq. (3) is that the combination of strength, modulus and density of a fiber (appropriately averaging in the corresponding properties of any matrix) will determine the ballistic performance of any target made from the fiber. For instance, at a constant fiber modulus, increase of the fiber strength will increase ballistic performance, whereas at constant fiber strength, decrease of the fiber modulus will increase the ballistic performance, following power laws as indicated.

It is the intention of the work reported here to investigate and possibly corroborate this relation between fiber properties and ballistic performance of a fiber composite through numerical simulations using a fully descriptive and simple physical model.

3. SUMMARY AND CONCLUSIONS

A numerical model for a fiber-based composite target impacted by a cylindrical projectile using basic physics and basic fiber properties has been investigated. The numerical model predicts ballistic limits in reasonable agreement with experimental values. The results obtained with the numerical model corroborate empirical and theoretical results in literature:

- a single master-curve relating ballistic limit and the ratio of target and projectile areal densities
- the quantitative power-law relations between fiber mechanical properties and ballistic limits

The validated numerical model relates material properties to fundamental ballistic understanding thus identifying directions for development of ballistic materials.

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NATO ASI "Defense Related Intelligent Textiles and Clothing
for Ballistic and NBC (Nuclear, Biological, Chemical) Protection

NUCLEAR THREATS, PHYSIOLOGICAL EFFECTS AND COUNTERMEASURES

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Key words: nuclear protection, nuclear suits, radiation protection, NBC, Radiation Shield Technologies, RST

1. NUCLEAR THREAT

The threat of nuclear radiation is driving global demand for more advanced personal-protection technologies. National security experts worldwide are searching for solutions to meet the demand for protection. These experts recognize that a terrorist attack involving a nuclear or radiologic weapon would be catastrophic. They theorize that if detonated in a large urban area, such as midtown New York City, a 10KT weapon could kill up to a half million inhabitants. A radiological weapon in the same location could cause up to a trillion dollars in short-to-long-term economic damage.

2. CURRENT PPE

Current nuclear, biological, chemical (NBC) suits and personal protection equipment (PPE) available today for first responders offer limited shielding against these and other threats and have no capability to protect against ionizing radiation. Until now, there has not been one solution to address every type of threat. Demron is the first to offer universal protection and the highest level of shielding.

3. UNIQUE NANOTECHNOLOGY: DEMRON

Demron's unique nanotechnology is currently used in full-body NBC suits, tactical anti-nuclear vests, high-energy nuclear suppression blankets and medical X-ray vests and aprons. It is also effective in radiation-proof tents, linings for aircraft and spacecraft and covers for radiation-sensitive equipment. The Demron material is composed of a broad spectrum of nano- and micron-scale constituents that work independently, as well as in unison, to provide uniform attenuation from radiation and chemical and biochemical protection. Each physical property of the Demron material, from radiation attenuation and abrasion resistance to flexibility, is engineered on the molecular level using novel molecular formulations and nano- and micron-scale additives to produce a unique, high-quality product.

4. RESEARCH AND DEVELOPMENT

Research and development efforts have focused on providing a solution to meet the growing threat of nuclear, biological and chemical radiation. Current PPE's only offer low-energy alpha protection without X-ray, Gamma or high Beta protection. They allow for heat stress to occur inhibiting operations among first responders.

Demron is the only CBRN component certified for meeting all Class 2 requirements of NFPA 1994/2007 Standard on Protective Ensembles for First Responders to CBRN Terrorism

Incidents, it protects against Alpha, Beta, and Gamma (low energy) nuclear emissions. Demron is resistant to tears and chemicals, more lightweight, flexible and impermeable to chemical- and biological-warfare agents than other fabrics, so it may be used in jumpsuits for emergency workers and first responders to disaster scenes.

The thin, compliant Demron fabric has proved its effectiveness against X-rays and nuclear emissions in tests at Lawrence Livermore National Laboratory, the Neely Nuclear Research Center at the Georgia Institute of Technology and the department of radiology at Columbia University's College of Physicians and Surgeons. Experts with the U.S. Department of Defense proved its effectiveness in protecting against common chemical-warfare agents such as mustard gas, VX nerve gas and sarin gas.

5. THE SOLUTION

As the threat of nuclear, chemical and biological agents continues to increase, government and security officials recognize the need for better protection. A growing number are turning to Demron as the solution.

DEVELOPMENTS IN DECONTAMINATION OF MILITARY SOLDIERS AND EQUIPMENT USING FIBROUS MATERIALS

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Key Words: Decontamination, Nonwoven Wipe, Chemical Warfare, Defense textiles.

1. INTRODUCTION

Realizing the current threat of toxic chemicals and chemical warfare (CW) agents, individual protection is important for warfighters and first responders, as well as the civilian population. Within the realm of individual protection, decontamination of warfare agents is not only required on the battle field but also in laboratory, pilot plants, production and agent destruction sites.

1.1 Scope of the Problem

Recent reports from the U.S. Department of Defense (DoD) to the U.S. Congress emphasize the importance of developing new personal decontamination systems which can remove and/or destroy ChemBio agents with minimal affect on the operational capability of military personnel. [1]. Additionally, the need for research in the area of development of lightweight, non-particulate, skin-friendly, non-aqueous, non-corrosive, environmentally safe, self-decontaminating, durable and less bulky protective materials which reduce physiological burden and provide improved protection against chemical hazards such as vapors and aerosols has been stressed [2]. It is of high importance to evaluate various decontaminants and decontamination techniques in order to implement the best practice in varying scenarios such as decontamination of personnel, sites and sensitive equipment (avionics, electronics, vehicle interiors and firearm systems).

1.2 Aim of the Investigation

In order to address the above mentioned requirements, a structurally well integrated, three layered fabric material with the nonwoven activated carbon (ACN) fabric layer sandwiched between two skin friendly non-woven fabric layers was manufactured at Texas Tech University using the H1 technology needle loom *Fehrer®AG* [3,4,5]. This paper describes the development of a non-particulate nonwoven composite and the evaluation of its adsorption capability for protection against toxic chemical ingress. This project is unique in the area of barrier systems and addresses the requirements of the U.S. Department of Defense (DoD) for seeking and evaluating highly efficient, non-particulate, and skin-friendly materials which provide necessary chemical protection while minimizing any discomfort or irritation.

2. MATERIALS & METHOD OF APPROACH

In order to maximize the chemical absorptive and adsorptive capabilities of the decontamination wipe and to ensure next-to-skin comfort, the protective composite substrate was manufactured in such a way that the material is composed of at least three layers: 1) Pre-filter layer (base substrate), 2) Middle adsorbent layer (ACN) and 3) Next-to-skin layer (base substrate).

Furthermore, this paper describes the quantitative comparison of adsorption potential of a nonwoven high surface area chemical protective fabric with U.S. DoD's currently fielded M291 Kit powder. A real time protocol to precisely quantify and compare the adsorption capacities of such fabric substrates using a thermogravimetric analyzer (TGA) is described in this study.

3. EXPERIMENTAL RESULTS & DISCUSSION

Based on visual examination it is evident that the nonwoven activated carbon materials are *devoid of loose particles* and therefore carry a high potential to effectively decontaminate sensitive areas such as eyes, open wounds and sensitive parts of military equipment. The quantitative and statistical analysis categorically compares the individual surface areas and adsorption capabilities of respective decontamination materials and their integral parts which are responsible for adsorption/retention of toxic chemicals agents. The results indicate that the adsorption capacities for the nonparticulate nonwoven composite and its intrinsic adsorption component (needle punched ACN) are significantly higher than those of the M291 Kit and its loose particulate decontamination powder.

4. CONCLUSION

Nonwoven composites incorporating layers of adsorbent and skin-friendly absorbent substrate can serve as viable substrates for decontaminating human body and military equipment as they are devoid of loose particles, drapable and flexible. The work in this paper is of national and international interest to the defense and first responder communities and opens-up a new window of high-end applications for sorbent nonwoven fabrics and nonwoven composites.

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Saturday 10th April 2010

Session chair : Prof. P. Kiekens

9.30-10.45 **Assessment of heat and mass transfer through protective clothing using thermal manikins: opportunities and limitations**
Dr. R. Rossi, EMPA, Laboratory for Protection and Physiology, Switzerland

11.15-12.30 **Rapid detection of biological weapons and evaluation of antimicrobial activities on textiles**
Prof. J. Freney, University of Lyon, Institut des Sciences Pharmaceutiques et Biologiques, France

16.00-17.15 **Advancements in intelligent textiles: The next generation of protective clothing**
Prof. S. Jayaraman, Georgia Institute of Technology, USA

Work in progress on protective clothing for NBC protection :

17.45-18.10 **Charged nanofibrous materials as traps for radioactive gas decay**
Prof. David Lukáš, Technical University of Liberec, Department of Nonwoven textiles/Nanoscience Centre, Czech Republic

18.10-18.35 **CFD for engineering textiles to protect against CB substances**
Dr. Xiaoming Zhao, Heriot-Watt University, Research Institute for Flexible Materials, UK

ASSESSMENT OF HEAT AND MASS TRANSFER THROUGH PROTECTIVE CLOTHING USING THERMAL MANIKINS: OPPORTUNITIES AND LIMITATIONS

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Key Words: human simulator, thermal manikin, thermophysiological simulation

1. INTRODUCTION

The clothing is the closest envelope of the human body, and hence, has the primary impact on thermal comfort, wet discomfort, and finally, the physiological response of the human body and environmental strain. On the other hand, the clothing microenvironment is affected by physiological reactions of the human body (e.g. sweating, temperature distribution).
Despite various advances, thermal manikins are not capable of adequately simulating the human thermophysiological response (body core and skin temperature distribution, onset of vasomotor reactions, sweating and shivering, survival time). Presently, manikins are usually operated at uniform steady-state surface temperatures and homogeneous sweat rates in comparative measurements described in current standards [1, 2]. Nevertheless, various attempts have been undertaken to mimic the thermal response of a human more realistically [3, 4], which indicates the growing interest in using physiological manikins. Ideally, such a human simulator should 'feel' and respond dynamically to the thermal environment as real humans do. This can be achieved by combining manikins with a mathematical model of human thermoregulatory system.
This paper discusses opportunities and constraints of thermal manikins with regard to their functionality when controlled by a mathematical model of human physiology using the example of the Sweating Agile thermal Manikin (SAM) [5] coupled with the FPC-model [6].

2. COUPLING ELEMENTS AND METHOD

The manikin SAM is a multi-segmental and anatomically-formed thermal manikin [5]. It consists of a skeleton with movable joints and is equipped with 22 shell-parts, which are separately heated on each inner surface and 125 sweat outlets evenly distributed on the manikin's surface. The model used as control system of the manikin is the FPC-model, which is able to simulate human thermal responses under both steady-state and transient conditions [6] and it has been validated over a wide range of environmental conditions (5°C to 48°C).
The coupling process [7] was accomplished in two stages. At first, the thermal manikin was set up to produce a homogeneous surface temperature and sweat rate over the entire surface of the manikin, though changing in time. In the second stage of the coupling process, the manikin was set up to produce heterogeneous surface temperatures and sweat rates amongst the shell parts. The coupling method was based on real-time iterative exchange of the relevant data between the manikin and the physiological model. The skin temperature and the sweat rates from the model were imposed in the manikin. The heat flux from the manikin was, then, used as the feedback signal, which represented the mean amount of heat exchanged with the environment for the clothing worn during a set time interval.

3. RESULTS

The manikin coupled with the physiological model was validated by comparison with the results from human subject tests for various environmental conditions. An example is shown in Figure 1.

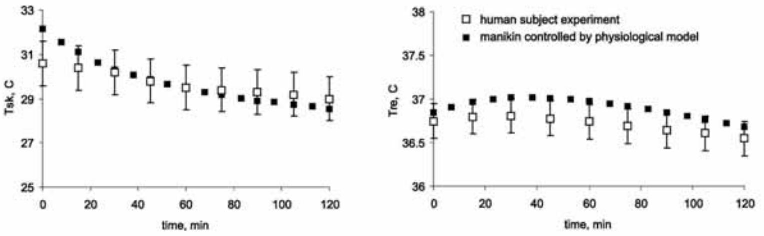

Figure 1. Mean skin and body core temperatures measured in human subjects [8] and using manikin controlled by the physiological model at Tair = 20°C for semi-nude, reclining subjects.

4. DISCUSSION AND CONCLUSIONS

The multi-sector human simulator with homogeneous surface temperature reproduced the thermal behaviour observed in human subject tests for tested conditions with good accuracy. Furthermore, an attempt to advance this human simulator to the one with the heterogeneously distributed surface temperatures proved unsuccessful. An uncontrolled heat exchange between the manikin elements and the environment seemed to unable use of power input as a precise indicator of the heat flux released at the manikin surface.

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RAPID DETECTION OF BIOLOGICAL WEAPONS AND EVALUATION OF ANTIMICROBIAL ACTIVITIES ON TEXTILES

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Key Words: biological, weapons, detection, textile, antimicrobial

1. INTRODUCTION

Recent bioterrorist events have emphasized the need to immediately detect and identify biothreat agents. Rapid and accurate identification of such agents is important not only to confirm that a bioterrorism event has occurred, but also to determine whether suitable measures should be implemented to protect public health.
In the field of textiles, it is important both to rapidly detect biological weapons which could be borne on textiles such as clothes but also to propose tests for the evaluation of antimicrobial textiles developed against biological agents.

2. RAPID DETECTION OF BIOLOGICAL WEAPONS

The list of biological agents usable for bioterrorism consists of 33 viruses, 14 bacteria, 11 toxins and 1 fungus. Today, of this list, only three microorganisms have to be taken into a particular consideration: *Bacillus anthracis* (causative agent of anthrax), *Yersinia pestis* (causative agent of plague) and smallpox virus (causative agent of smallpox).

2.1 Sampling

In the case of textiles, efficient sampling is essential. Microbiological surface sampling involves selecting a representative portion of the surface to be studied and collecting microbial contaminants from that surface with appropriate sampling devices. There are some variables which may affect sampling, like the ability of the agent to survive or produce active toxins on a surface for extended periods. For example, spores of *Bacillus anthracis* have long been known to persist for years on surface such as paper. In the case of nonporous surfaces such as textiles, different sampling methods can be used, such as wipes, swabs, agar contact plates, HEPA vacuum collection socks, and microvacuum sampling.

2.2 Detection methods

There are two different methods: non-discriminatory and discriminatory methods.
In the case of non-discriminatory methods, aerosol particle sizers (APS) were proposed for the detection of particles the size of which is between 1 and 5 μm. Aerosols particles sizers (APS) take advantage of these sizes for detecting bioterrorist agents. A strongly uniform particle distribution in the characteristic size range may be indicative of the presence of a biological agent.
The discriminatory methods take advantage of one of two facts of all living cells: (*i*) all microbes possess unique molecules on their surfaces that can be bound by components of the immune system, or (*ii*) these unique molecules are encoded by unique stretches of DNA contained inside every cell. These methods include:

- Immunoassays. Disposable handheld assay (HHA) test kits or tickets for detecting biological warfare (BW) agents have been available since the early 1990s. These tickets resemble and function similarly to home pregnancy tests by a process called immunochromatography.
- DNA-based assays. DNA-based assays and immunoassays work because they use reagents (antibodies or DNA probes) specific for each pathogen.
- Mass spectrometry (MS). Unlike DNA-based assays and immunoassays, no pathogen-specific reagents are required, so MS can be used to identify multiple pathogens and provide clues to the identity of microorganisms that might not be expected in advance.
- Hybrid systems.

As noted, each previously described technique has its own advantages and limitations. Thus, there have been several attempts to use immunoassays, DNA-based methods, and MS in various combinations to capture the advantages of each technique employed while eliminating most limitations.

3. METHODS USED FOR THE EVALUATION OF ANTIMICROBIAL ACTIVITIES OF TEXTILES

In order to determine the efficacy of antibacterial textile, two categories of methods are generally used: the agar diffusion tests and the suspension tests. The bacterial species, *Staphylococcus aureus* (Gram positive) and *Klebsiella pneumoniae* (Gram negative) are recommended in most test methods. They represent the main types of resistance to biocides.

Agar diffusion test: if the antimicrobial agent can diffuse into the water of the agar, a zone of inhibition becomes apparent and its size provides some indication of the potency or the antimicrobial activity or the release rate of the active agent. If the agent is not soluble in water or is not released from the textile, the absence of bacterial growth underneath the fabric sample indicates the presence of antibacterial activity. These tests include AATCC 147-2004, JIS L 1902-2002 and SN 195290-1992 and they are only qualitative.

Suspension test: a small volume of bacterial inoculum in a growth media is absorbed into the fabric (absorption method). After 24 hours of incubation, the bacteria are eluted to be enumerated. This population is compared to the initial one. In order to ascertain that the decrease in bacterial number is truly due to the antimicrobial finish, we have to use control fabric without activity. When the textile cannot absorb liquid, the bacteria are directly deposited on the textile by means of a contact between bacteria spread onto agar and the textile (transfer method).

This type of test is exemplified by ISO 20743. The bacteria are deposited on the textile according to 3 different protocols: the first is identical to that used in JIS L1902 (absorption method), the second to the standard XPG 39 010 (transfer method) and the third is specific to this standard (printing method). The absorption method is used for hydrophilic textiles, the second for the hydrophobic ones and when we want to test the sides separately, the third which requires a particular device is not widely used. In order to more closely mimic the real-life situation, the ISO method recommends the use of bacterial cells suspended in heavily diluted nutrient media (1/20) to limit nutriment levels. Moreover, this method uses a calculation which permits the use of a control different from the sample that has gone through the same processing except antimicrobial finishing. Other methods are less used in Europe: AATCC 100-2004 and SN 195924-1992.

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ADVANCEMENTS IN INTELLIGENT TEXTILES: THE NEXT GENERATION OF PROTECTIVE CLOTHING

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Key Words: Interactive textiles, functional clothing, physiological parameters, energy harvesting

ABSTRACT

The field of intelligent textiles is rapidly emerging and transforming the traditionally passive materials into interactive structures. These advancements pave the way for the development of the next generation of protective clothing with specific functionalities.

In this paper, we will review the major advancements in materials and manufacturing processes that can be successfully utilized to create the next generation of protective clothing to guard against nuclear, biological and chemical threats. We begin with an assessment of the developments in clothing for monitoring the physiological parameters of the individual and the role of conductive materials and manufacturing technologies in facilitating these advancements. We then explore harvesting energy through clothing that can aid in the protection of the individual, especially in battlefield scenarios where power (energy) may be scarce. Following this, we discuss materials and technologies for keeping the wearer comfortable in extreme climates. We conclude the paper with a look at the challenges and emerging opportunities for further advancements in the field of intelligent clothing for individual protection and safety.

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CHARGED NANOFIBROUS MATERIALS AS TRAPS FOR RADIOACTIVE GAS DECAY PRODUCTS

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Key Words: Electrospinning, nanofibres, counterion condensation, radioactive decay

1. INTRODUCTION

Electrospinning is a simple and inexpensive method to produce micro- or nano-fibers from polymeric solutions or melts in an external electrostatic field. Production of electrospun fibres is accompanied by various kinds of irradiations. The first report was by Zeleny [1], who referred about radiation in the vicinity of polymeric jet origins, so-called Taylor cones. The kind of radiation to be described and discussed further, is radioactive irradiation, caused by trapping of Radon decay daughter isotopes on charged electrospinning jets.

2. ENTRAPMENT OF RADON DECAY PRODUCTS

Radon, ^{86}Rn, is present in air as the chemical element with atomic number 86. It is an invisible, radioactive noble atomic gas that in nature results from radioactive decay of some forms of Uranium, U, that is spread all over the world in igneous rock formations beneath buildings or in certain building materials. Uranium decays to Radium and Radon is being continuously produced by radioactive decay of Radium isotope ^{226}Ra. The most stable Radon isotope, ^{222}Rn, has a half-life of 3.8 days. Radon gas and its solid decay products are recognized and considered to be a serious health hazard since they are carcinogens.

2.1 Radon decay products deposition during electrospinning

The deposition of Radon decay products on electrospun nanofibrous materials was studied using a Geiger-Muler Tube. Radon decay progeny are not gases (*Po, Bb, Bi*) but solids. They can attach themselves to tiny particles in the air, and these particles may be trapped as contamination in the lungs of a human being breathing the air, and cause lung harm from subsequent alpha and beta radiation.

The deposition of Radon during electrospinning is explained here by an attraction between radon daughters charged objects. Particularly, Radon daughters have the electric affinity to conversely charged surfaces since they are electrically positive or negative as a result of stripping of electrons or α particles from the parent atom during their radioactive decays. Human health hazards increase this in modern industrial age as a human body often carries a negative static charge caused by nonzero body potential, up to tens of kilovolts, that results from everyday activities such as walking across synthetic floors, working with plastic materials or from coming into contact with charged objects.

2.2 Experimental

A series of electrospinning experiments have been carried out to confirm that even scant mass of electrospun nanofibrous layer, not more than tens of grams, can exhibit high-energy excitations that should be more than four times higher than the natural background. The electrospun materials were prepared in an environment with radioactive background having a gamma dose rate of (123 ± 8) nSv/h, where the symbol Sv in SI system of units is the Sievert. The radioactivity was registered by twin Geiger-Muler Tubes of the Radiometer 'VOLTCRAFT HS - 036'.Depositions on nanofibrous layers were measured with negatively and positively charged collectors [2].

For all samples the same half-time with various radiation intensities was measured. Irradiation intensities detected from nanofibres collected on positively charged collectors was about half than that of negatively charged ones under the same conditions. More complex measurements proved that Radon daughter deposits are more attracted by motionless negatively charged nanofibrous layers trapped on a collector than by a negative jet discharge attracted by a positively charged collector. The fundamental general theory explaining the process of Radon deposition in detail was introduced by Batkin *et. al.* [3].

3. CONCLUSION

Charged Radon daughters are probably trapped in the vicinity of highly charged nanofibres by the mechanism called Counterion Condensation [4]. More explanation of this phenomenon in a gas environment is needed.

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CFD FOR ENGINEERING TEXTILES TO PROTECT AGAINST CB SUBSTANCES

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Key Words: Computer Fluid Dynamics, Textile Fabrics, Filtration, Chemical and Biological, Aerosol testing.

ABSTRACT

CFD modelling and CAE techniques have been applied to textile woven structures and membranes in order to define their performance against CB substances. Each fabric layer is considered as a porous medium with spatial and time-varying properties. Multiple fabric layers and air gaps between layers are being successfully addressed. The model allows fabric interactions with our body and its surrounding environment. Substantial new capabilities for transportation of CB processes through the fabric using mass transfer modelling can be achieved.

$$u = -\frac{k}{\eta}\nabla p + \eta \nabla^2 u$$

k- permeability of the porous media,
η - fluid viscosity,
p - the pressure and
u - the superficial flow velocity of the fluid.

The permeability k, is taken as a constant, i.e. an intrinsic property of the porous medium.

$$\rho\frac{\partial u}{\partial t} - \nabla \cdot \eta(\nabla u + (\nabla u)^T) + \rho(u \cdot \nabla)u + \nabla p = F$$

η - dynamic viscosity (kg m-1s-1),
u - velocity vector (ms-1),
ρ - density (kg m-3),
p - pressure (Pa).

To calculate the CB agent concentration profiles through fabrics, the flow velocity distribution within the fabrics *U (u, v, w)* must be defined which involves the equation of fluid motion in porous media.

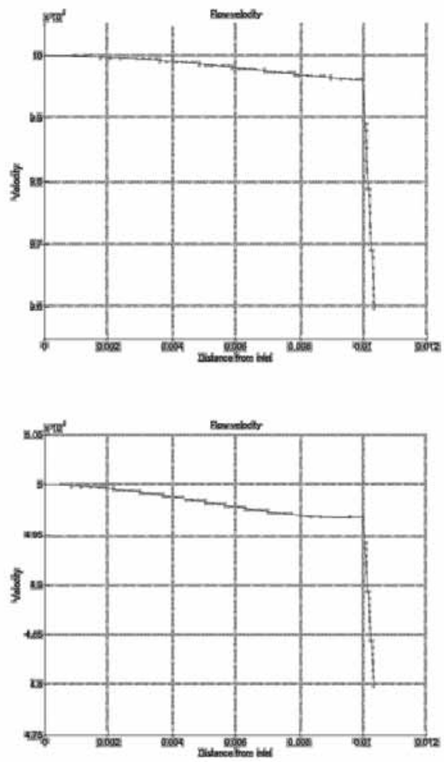

Figure 1. Velocity profiles through fabric at different flow rates (0.01, 0.005 m/s)

The main project application requirement is to allow oxygen inhalation whilst resisting CB agents for 20 minutes. A new aerosol measurement apparatus has also been developed capable of electronically measuring particles in the range of 10 nanometer.

The project collaborates with a number of companies and current research identified means of modifying existing fabrics and/or the designing of new ones with promising capability of CB protection.

Monday 12th April 2010

Session chair : Prof. S.S. Ramkumar

9.30-10.45 **Intelligent textiles for chemical biological protective clothing**
Dr. E. Wilusz, Natick Soldier RDE Center, USA

11.15-12.30 **Nanofunctionalised textiles and clothing for multiple personal protection**
Prof. P. Kiekens, Ghent University, Department of Textiles, Belgium

16.00-17.15 **Defining the limits of human thermotolerance while wearing protective clothing**
Dr. T. McLellan, DRDC Toronto, Canada

17.45-19.00 **Optical wearable sensors for NBC detection**
Prof. A. Lobnik, University of Maribor, Slovenia

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INTELLIGENT TEXTILES FOR CHEMICAL BIOLOGICAL PROTECTIVE CLOTHING

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1. ABSTRACT

Today's chemical biological (CB) protective clothing is fabricated from a wide variety of textiles and other materials in order to meet its demanding requirements. Materials range from multilayer textile systems containing activated charcoal to fiber reinforced thermoplastics. This clothing does a good job in providing the necessary protection, however the clothing is generally heavy, uncomfortable, and can subject the wearer to heat stress under moderate workloads. Lighter weight, more comfortable clothing is available with corresponding sacrifice in level of protection [1].

Advances in materials science, catalysis and nanotechnology have made novel materials and treatments available for application to the next generation of CB protective clothing. Membranes have been developed which act as barriers to hazardous chemicals while still allowing moisture vapor transport to occur through the material for some degree of heat stress relief through evaporative cooling. Techniques to optimize the transport properties of these membranes have been developed. These include ion implantation as well as the formation of self-assembled monolayers on surfaces. Research is underway to develop fabric systems which contain catalysts which demonstrate activity in promoting the destruction of hazardous chemicals. Superhydrophobic and superoleophobic treatments have been developed for outer shell fabrics which allow liquid droplets to roll off fabrics easily. This ease of shedding droplets minimizes the contact time between the liquid and the fabric, thus increasing the protection level afforded by the garment. Responsive materials have also been developed which provide garments with controllable, variable permeability. One of these systems is based on the use of perforated and layered membrane materials, where the holes in each layer are out of registration. Another system under development involves interpenetrating polymer networks where the conformations of side chains change in response to external stimuli.

Catalysts are under development which are intended to cause the transformation of hazardous chemicals into less toxic ones. These catalysts, when incorporated into fabric systems, will serve to reduce the hazard from chemical contamination, particularly while doffing the contaminated clothing. One of the catalysts of interest is organophosphorous acid anhydrolase (OPAA) which has been shown to be effective in neutralizing organophosphorous-type compounds. Amidoximes have also been shown to be effective against this class of chemicals. Polyoxometallates, which can be synthesized in an almost unlimited variety of compositions, are also of interest, especially in regard to neutralizing mustard. N-halamine and quarternary ammonium salts with alkyl side chains are also being investigated for use as biocides.

Superhydrophobic and superoleophobic treatments are making it possible for fabrics to easily shed water or liquid chemical droplets. Minimal contact time between the fabric and droplets minimizes the chances for the liquid to permeate. A significant amount of research has been dedicated toward developing surfaces with the appropriate texture to produce the desired properties. For a surface to have the optimal design requires a combination of good material or coating selection in order to minimize the surface energy and appropriate surface texture. By adjusting the interactions between the surface and the contacting liquids, a wide range of wettability can be produced, ranging from superwetting to supernonwetting. Fluorodecyl POSS (polyhedral oligomeric silsequioxane) has one of the highest surface energy values reported to date, and fabrics coated with it have been shown to demonstrate omniphobic surfaces.

Controllable, variable permeability is a desired property for future generations of CB clothing. This responsiveness can be demonstrated in a number of ways. One way might be to envision a polymer system or surface containing side chains where the chains change their conformation in response to an external stimulus, thus opening or blocking pores in the material. Another technique which has been demonstrated involves the use of thin, barrier membranes laminated between two fabrics. The membranes are perforated with small holes and separated from each other with spacers. The holes in one membrane are out of registration with the other. Air and moisture vapor are able to be transported through the material system. The material is "breathable." Upon applying a voltage to the system the membranes, which contain a conducting element, collapse against each other, thus blocking the pathways for air and moisture vapor transport. The material system then becomes an "impermeable" barrier. Prototype garments have been fabricated from such a material system, and these garments have been evaluated.

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NATO ASI "Defense Related Intelligent Textiles and Clothing
for Ballistic and NBC (Nuclear, Biological, Chemical) Protection

NANOFUNCTIONALISED TEXTILES AND CLOTHING FOR MULTIPLE PERSONAL PROTECTION

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Key Words: nanotechnology, nanofibres, nanofunctionalisation, nanotreatment.

1. INTRODUCTION

By applying nanotechnology to textiles and clothing soldiers can perform complicated and unique functions by an improved ballistic protection, by better camouflage, by getting more power to react, and in general by getting an enhanced overall protection against external conditions through functionalized (nano) fibres and fabrics.

2. NANOTECHNOLOGICAL DEVELOPMENTS

Shear thickening fluids increase remarkably the potential of high-performance bullet-proof vests based on aramid and high-performance polyethylene fibres (Spectra, Dyneema, …). This means that hard parts (ceramics) may not be needed anymore and so protective clothing remains flexible.
Fabrics are being developed which change all of a sudden from flexible to stiff under a ballistic threat. This can be the result of fluids solidifying reversibly after activation.
Camouflage is extremely important for soldiers. Coatings can be developed that change colours (patterns) depending on the environment, i.e. desert landscape, environment with vegetation, etc…
Conductive polymers can be integrated in fabrics in order to give textiles a power function (artificial muscles) and/or to harvest energy for communication…
Zeolites may hinder radioactive contamination; an example to achieve this is the use of clay : montmorillonite. Also activated carbon is an excellent (nano) material for decontamination.
Superhydrophobic and superoleophobic treatments on fabrics allow giving a maximum comfort to clothing of soldiers. Several new developments based on nanotechnology are available.

3. CONCLUSION

Nanotechnology applied to textiles and clothing contributes to a large extent to a safer behaviour of soldiers in a variety of severe circumstances.

NATO ASI "Defense Related Intelligent Textiles and Clothing
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DEFINING THE LIMITS OF HUMAN THERMOTOLERANCE WHILE WEARING PROTECTIVE CLOTHING

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Key Words: uncompensable heat stress, aerobic fitness, hydration, heat acclimation

1. INTRODUCTION

Requirements for the military to wear protective clothing, such as fragmentation vests alone or in combination with biological and chemical ensembles, and carrying heavy loads during exposure to hot environments can quickly lead to conditions of uncompensable heat stress (UHS) where core temperatures can increase to dangerously high levels. Intervention strategies designed to reduce the heat strain during UHS do so by affecting the initial core temperature, the final core temperature tolerated at exhaustion or the rate of increase in core temperature from the beginning to the end of the heat stress exposure.

2. METHODS

Studies involve monitoring rectal (T_{re}) and skin temperatures, heart rate and metabolic heat production while subjects walk on treadmills in various environmental conditions (30-40°C, 15-65% relative humidity). Subjects are typically in NATO Dress State 4+Mask and continue to the point of exhaustion or until an ethical ceiling for T_{re} of 40.0°C or 95% of maximal heart rate is reached.

3. RESULTS

Under conditions where evaporative heat loss is restricted, heat acclimation can increase thermotolerance by only about 15-20% due to the lowering of resting core temperature [1]. Similarly, poor management of hydration prior to heat stress exposure can lead to an elevation in resting core temperature and reduce tolerance time again by about 20% [1, 2]. Maintaining proper hydration throughout the heat stress exposure can also increase the core temperature tolerated at exhaustion [3] and is a critical factor for maintaining cardiovascular stability during weight-bearing activity at high body temperatures [3, 4]. The ingestion of cold water prior to and during UHS can also act as a heat sink and increase total heat storage capacity [5, 6]. A high body fatness hastens the rise in body temperature for a given rate of heat storage due to the lower heat storage capacity of adipose versus lean tissue [7]. By far the most influential personal factor for increasing thermotolerance during UHS is a high level of aerobic fitness. Regular endurance exercise training increases the core temperature that can be tolerated at exhaustion during weight-bearing activity in the heat and increases exposure time by over 60% compared with sedentary individuals [7]. This advantage for the endurance trained reflects not only an expanded blood volume that helps maintain the gut barrier integrity to prevent endotoxin leakage but also an enhanced cellular cytoprotective response to any level of circulating endotoxin. Recent studies have shown an earlier and more pronounced leakage of endotoxin as core temperature increases for the sedentary individual together with a greater proinflammatory response and cellular apoptosis compared to the endurance trained [8, 9].

4. CONCLUSIONS

The aerobically fit soldier who maintains proper hydration before and during heat stress exposure will be able to march further, fight longer, and make better decisions than the unfit soldier in hot environments while wearing protective clothing.

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NATO ASI "Defense Related Intelligent Textiles and Clothing
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OPTICAL WEARABLE SENSORS FOR NBC DETECTION

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Key Words: optical chemical sensors, intelligent wearable textiles, safety, higher added value products

1. INTRODUCTION

Nuclear, biological and chemical weapons represent a constant threat for mass destruction worldwide, which may potentially endanger a lot of people on their short term exposure. The development of an early warning system, based on the detection of their toxic substances is therefore an important issue for research and development. The interest for small, robust and sensitive sensors, which can be embedded into textile structures, is increasing [1].

Wearable sensors can be used to provide valuable information about the wearer's health and/or to monitor the wearer's surrounding environment, to identify safety concerns and to detect threats, during the wearer's daily routine within his natural environment. The "chip on a textile" – an integrated chip, capable of data analyzing – enables an early detection. A chip connected with a smart delivery system can provide: a) simultaneously comfort and monitoring (for safety and/or health), b) non-invasive measurements, c) no laboratory sampling, d) continuous monitoring during daily activity of the person, and e) possible multi-parameter analysis and monitoring. However, in order for the technology to be accessible, it must remain innocuous and impose minimal intrusion on the daily activities of the wearer. Therefore, wearable technologies should be soft, flexible, and washable to meet the expectations of normal clothing. Data transmission must be wireless to allow free movement of the wearer. Conventional methods for monitoring toxic substances require special handling of the tested sample; they are expensive and do not allow in-situ and remote sensing. In contrast, optical chemical sensors used as wearable technology and including optical fibres are advantageous over conventional analytical methods, because they are immune to electromagnetic interference, small and compact in size, flexible, sensitive, able to be multiplexed, they allow in-situ remote sensing and may be embedded into textile structures [2-4].

Besides using classical protective equipment, a textile integrated sensor system can assure to an individual an incomparably higher safety and enable him to react more rationally in the threatening environment. An optical sensor system can be expanded into a larger system, including more optical sensors that may serve as reserve or enable the detection of several toxic substances at the same time. Examples of the following considerations have to be taken into account when designing the wearable optical sensor technologies: the sensor system does not prevent the wearer's movements, the sensor system performance is not disturbed, and the functionality of the textile material (e.g. part of the wearer's garment, patches, filters, etc.) upon sensor system integration is not altered. The sensor can be directly coated on the textile structure or incorporated in it via the optical fibres.

Creating intelligent textiles integrating sensor devices therefore offers the possibility to access information anywhere and at anytime necessary and can thus save people's lives. The incorporation of optical chemical sensors into textiles adds a new dimension to the field of smart clothing. Smart textiles open a new market niche that can give new products with a high-added value. The application possibilities of optical chemical sensors integrated into textile materials are only limited by our imagination and creativity.

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Tuesday 13th April 2010

Session chair : Prof. F. Boussu

9.30-10.45 **Heat strain alleviation in protective clothing**
Prof. H.A.M. Daanen, TNO Defence and Safety, The Netherlands

11.15-12.30 **Ballistic performance of Dyneema® at elevated temperatures, extreme for body armor**
Mr. H. Meulman, DSM Dyneema, The Netherlands

16.00-19.00 **Poster session**

Dynamic modulus measurement for protective textiles in ballistic prevention
Filiz Avsar, Lawson Hemphill, USA

Factors that contribute to garment thermal performance – instrumented mannequin flash fire evaluation system and modelling
Guowen Song, University of Alberta, Edmonton, AB Canada

The idea of electromagnetic dumping effect of hybrid yarns with conductive solenoids and ferromagnetic core
Grabowska K., Technical University of Lodz, Poland.

Advanced NBC-Protection System (ANBCP-S)
Frank Messer, Autoflug GmbH, Germany

A snapshot of smart textiles in military applications
Lina Rambausek, Ghent University, Department of Textiles, Belgium

Ballistic protection for personal body armour against fragments and bullets
Ela Ramer, dipl. ing. and Svetlana Grković, dipl. ing., BOROVO – GUMITRADE d.o.o. - Vukovar – Croatia

NBC Isolation protective equipment (protective suits, footwear and covers)
Svetlana Grković, dipl.ing. and Ela Ramer, dipl.ing.; BOROVO – GUMITRADE d.o.o. - Vukovar – Croatia

Real-time innovative image system for registration of ballistic body armor deformation
Zbigniew Stempien, Technical University of Lodz, Poland

Novel intelligent textile based on silicon flexible skins
Ahmed Thniabat, University of Jordan

Transplanar absorption of liquids by fabrics
Viktoriia Vlasenko, Kiev National University of Technologies and Design, Ukraine

NATO ASI "Defense Related Intelligent Textiles and Clothing
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HEAT STRAIN ALLEVIATION IN PROTECTIVE CLOTHING

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Key Words: hyperthermia, cooling systems

1. INTRODUCTION

The most important mechanism that humans have to release is body heat during heavy work, i.e. the evaporation of sweat. This cooling mechanism is seriously compromised when working in protective clothing (PPE). The water vapor barrier of PPE results in a high absolute and relative humidity in the air layer between the skin and PPE. The resulting evaporation efficiency, defined as the ratio between secreted and evaporated sweat, is therefore low. To reduce the heat strain problems, personal cooling systems may provide a partial solution. The major advantages and disadvantages of cooling systems related to PPE will be discussed.

2. PERSONAL COOLING SYSTEMS

The main methods used to cool the human body can be distinguished as fluid cooling, air cooling and the use of phase change materials. Other cooling methods are emerging onto the market and will be discussed briefly.

2.1 Fluid cooling

Fluids have a higher heat capacity compared with air and are therefore well-suited to dissipate body heat. Although liquids such as glycol have a higher heat capacity than water, water is preferred in practice since fewer problems (better 'graceful degradation') occur in the case of leakage. For an effective water cooling system, a suit with tubes inside, a pump and cooling device (heat exchanger) are necessary. The main disadvantage of such a cooling system is the weight and volume which makes them unacceptable for the dismounted soldier. Also, the tubed suit itself is a thermal barrier that may increase thermal strain in the heat. In a transport system, such as a helicopter or a car, the pump and cooling device can be mounted in the vehicle and the subject can plug in.

Cooling is not effective when the body core drops below a certain threshold. When cooling continues, vasoconstriction in the skin reduces the cooling efficiency [1]. Moreover, thermogenesis may occur, counteracting the cooling effect. Therefore, advanced water cooling systems only function when skin temperature is higher than a preset threshold [2].

2.2 Air cooling

Air cooling can be distinguished between systems that use cooled air and systems that use ventilation as the cooling principle. An air-cooling system is often bulky, although progress is being made in miniaturization. A vortex pipe splits ambient air into cold and warm air, but needs high pressures in order to be effective. Air ventilation systems blow in ambient air. Even at high ambient temperatures, ventilation cooling can increase the sweat efficiency and thus improve the thermal balance [3]. The main challenge for air cooling systems is to provide sufficient amounts of clean air in a contaminated environment. Ventilation cooling systems are based on sweat evaporation, and thus it is important to consider that the lost fluid has to be compensated by fluid intake, in order to maintain the performance level.

2.3 Phase change materials

Ice can be considered as the most simple phase change material (PCM): during the transition from solid to liquid heat is dissipated to the environment. Vests containing ice are effective as personal cooling device in mines, but for the armed forces logistical issues play a role during operation in the heat. Paraffin is an interesting PCM since the melting point is close to skin temperature. This material is commercially available in microcapsules fixed to the inner side of the garment. In this way the PCM functions as a thermal buffer: it generates heat when the body is cooled and dissipates heat when the body is getting warmer. A disadvantage is that several kg of PCM is necessary to be operationally effective.

2.4 Other methods

Although most cooling systems aim at cooling large surface areas in the garments, it is worth considering cooling of the extremities. In particular, immersion of the hands in cold water is an effective way to lose heat [4].
A relatively new method is the use of endothermic salts. The salts dissipate heat when they become dissolved in water. In the European Prospie project (www.prospie.eu) the efficiency and applicability of these salts will be investigated.

In summary, working in PPE leads to heat strain due to sweat evaporation restrictions. Partial counteraction of heat strain by personal cooling systems is possible for military in vehicles. The main challenge is to adapt the systems in such a way that the dismounted soldier may also benefit from cooling techniques.

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BALLISTIC PERFORMANCE OF DYNEEMA® AT ELEVATED TEMPERATURES, EXTREME FOR BODY ARMOR

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Key Words: ballistic protection, high temperature

1. INTRODUCTION

During the development of the NIJ 0101.06 standard [7] one of the key issues was the development and selection of a test method (artificial ageing method) that could predict long term performance of armor. This has led to a series of studies within DSM on Ultrahigh Molecular Weight Poly-Ethylene (UHMW-PE) Dyneema® fiber and UD. This article will describe the results of these studies on the effect of elevated temperatures, showing that applications made of Dyneema® UD will keep their ballistic performance even at temperatures higher than the 65°C specified by NIJ 0101.06. Mechanical wear was not taken into account in this study.

2. BALLISTIC PERFORMANCE OF FIBER-BASED ARMOR AFTER CONDITIONING AT HIGH TEMPERATURES

In [5] a model is presented which relates the fiber properties of fiber based armor to the V50 of a specific threat. A parameter Ω (having m^3/s^3 as unit) which is the product of fiber specific toughness (i.e. energy to break per kg of material) and the velocity of sound in the fiber contains the fiber properties. This parameter Ω can be considered as an indication for the ballistic performance and is used to study the influence of temperature on the ballistic performance of armor based on Dyneema® fiber. Tests have been conducted with the Dyneema® ballistic SK76 1760dtex fiber at a range of temperatures (-20°C – 100°C) with different strain rate (3.5 – 350 % /second) to look for temperature influence on the performance. The results of these tensile tests were used to calculate $\Omega^{1/3}$. It was observed that $\Omega^{1/3}$ depends on both temperature and strain rate. $\Omega^{1/3}$ drops at increasing temperature for constant strain rate. At constant temperature it increases for increasing strain rates. At 100°C and the highest strain rate the parameter $\Omega^{1/3}$ is still around 95% of the value calculated for 23°C and quasi static strain rate. It should be noted that the applied strain rates are still rather low, compared to strain rates experienced in real bullet – body armor interaction. Based on these trends it is expected that tests at high temperatures with realistic strain rates would show higher values for $\Omega^{1/3}$ and therefore increased ballistic performance. Based on this study, which is conducted on fiber only, it is expected that products made of Dyneema® UD still should show good ballistic resistance when tested at elevated temperatures, even higher than the recorded temperatures, observed in civil vehicles (maximum is 67°C, as published in [6]).

Taking the above theoretical model into consideration it was decided to condition armor samples at high temperature and conduct V50 tests (according to STANAG 2920, see [1]). In [4] it has been shown that Dyneema® fibers kept their strength and tenacity after being conditioned to temperatures of 65°C up to 8 weeks. It was decided to go further and evaluate the effects on ballistic performance after conditioning at even higher temperatures. These V50 tests were conducted at room temperatures as conducting shooting tests with samples at high temperatures was considered as being too complex. The results of these V50 tests showed that Dyneema® UD in soft ballistic packages keeps its performance even after being conditioned at high temperatures as no significant change was observed in performance after the samples were conditioned at 75°C for 8 weeks. Hard armour panels, made of Dyneema® UD did show no significant change in performance, even after the conditioning of 20 weeks at 90°C.

Finally, a vest sample passed all test criteria for NIJ 0101.04 level 3A (see test report [3]) after it was climate conditioned according to the German standard for body armour [2]. From these test results together with the theoretical background as presented above, DSM concludes that products made of Dyneema® keep their performance even after being exposed to temperatures, far above usage temperatures for body armor.

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DYNAMIC MODULUS MEASUREMENT FOR PROTECTIVE TEXTILES USED IN BALLISTIC PREVENTION

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Key Words: protective textiles, dynamic modulus, ballistic, paraaramids, UHMPE

1. INTRODUCTION

Worldwide consumption and the production of technical textiles have been increasing. The biggest growth areas are transport textiles, followed by geotextiles, protective textiles and medical textiles [1]. This poster looks at the principles of Dynamic Modulus testing and its importance for protective textiles that are used in ballistic prevention.

2. BASIS OF BALLISTIC PREVENTION

Protective textiles, especially the ones that are used in ballistic prevention need to stop the projectile flight in the shortest distance possible. The best protection at the lowest weight is a combination of high specific modulus as well as tenacity and elongation at break.

Since the basis of ballistic prevention is to extract the maximum energy from the incoming projectile, absorption of the kinetic energy of the projectile needs to be studied. This absorption is related to the wave propagation and frictional energy dissipation [2].

Wave propagation velocity, c is given in the Equation 1 below:

$$c = \left(\sqrt{\frac{Young's\ Modulus}{\rho}} \right) \tag{1}$$

where, c is m/sec, Young's Modulus is N/m^2 and ρ is the density of the material in kg/m^3.

2.1 Measuring Wave Propagation Velocity with Dynamic Modulus Tester

Lawson Hemphill Dynamic Modulus Tester, DMT is a device designed to measure the Sonic Velocity through the materials. The DMT can be used for yarns as well as strips of most materials. Figure 1 shows the DMT configurations.

Figure 1. Lawson Hemphill Dynamic Modulus Tester, DMT and its configurations

2.2 Dynamic Modulus Measurement Samples for Protective Textiles

Figure 2 below shows the sonic velocity measurement of Steel Wire with DMT.

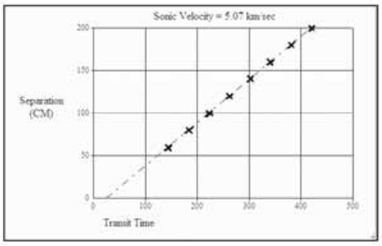

Figure 2. DMT Sonic Velocity measurement of Steel Wire

Figure 3 shows the actual DMT sonic velocity measurements for Steel, Nylon yarn, paraaramids and UHMPE respectively. Paraaramids and UHMPE are commonly used in ballistic protection.

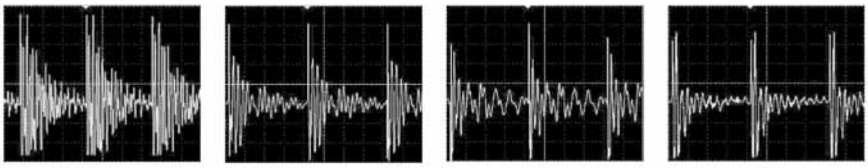

Figure 3. DMT Sonic Velocity measurement of Steel Wire, Nylon TireCord, Paraaramid and UHMPE, from left.

The data show that sound velocity is 5.07km/sec for steel, 3.63km/sec for tirecord nylon, 7.23km/sec for the paraaramids sample and 7.59km/sec for the UHMPE sample.

When looking for a product for ballistic protection, the goal is to have the highest wave propagation speed to stop the projectile at the shortest distance possible. DMT results clearly show why UHMPE and pararamids are the most commonly used materials in this field.

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FACTORS THAT CONTRIBUTE TO GARMENT THERMAL PERFORMANCE – INSTRUMENTED MANNEQUIN FLASH FIRE EVALUATION SYSTEM AND MODELLING

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Key Words: clothing protective performance, mannequin flash fire evaluation system, modelling

POSTER ABSTRACT

The size and distribution of air gaps between a mannequin and thermal protective coveralls were determined by using a three-dimensional body scanner. A flash fire instrumented female mannequin evaluation system was employed to investigate the effect of garment style and fit on thermal protection. Findings demonstrated that the size of the air gap showed a good correlation with the time to burn injury and the energy absorbed. Garment style and fit influence protection, as the inappropriate fit of style exhibits susceptibility to burns. Additionally a numerical model developed for flash fire mannequin system was applied to study the garment factors and their effect on thermal protection. The results from the numerical model help to contribute to a better understanding of the heat transfer process in protective garments exposed to intense flash fires, and to establishing systematic methods for engineering materials and garments to produce optimum thermal protective performance.

THE IDEA OF ELECTROMAGNETIC DUMPING EFFECT OF HYBRID YARNS WITH CONDUCTIVE SOLENOIDS AND FERROMAGNETIC CORE

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Key Words: electromagnetic fields, hybrid yarns, fancy yarns, magnetic component, solenoids.

1. POSTER ABSTRACT

The aim of this work is to design the process of the new generation of textile protective fabrics with proprieties against professional exposure to electromagnetic radiation (EMR), the sources of which are: antenna's installations, capacitive welders and microwaves, apparatus for electrosurgery, micro and short-wave diathermy. The proposed innovatory solution for the individual textile protection before EMR consists in use of the hybrid threads with punctual effects in the solenoid shape. The foreseen advantages resulting from the realization of this idea consist in, first of all, man's safety in the strong EMR zone as well as in the optimization of the comfort of work in threatening health conditions, and also in the introduction of a new technology of the barrier fabrics which enlarges the potential sector of textile companies.
The originality of this solution consists in finding an analogy between the specific structure of the bunch fancy yarn (Fig. 1) and the circuit with solenoids arranged in rows (Fig. 2). The use of the electroconductive yarns (copper) as component effect yarn will permit the creation of the solenoids on a ferromagnetic core yarn (steel).

Figure 1. The structure of a bunch fancy yarn.

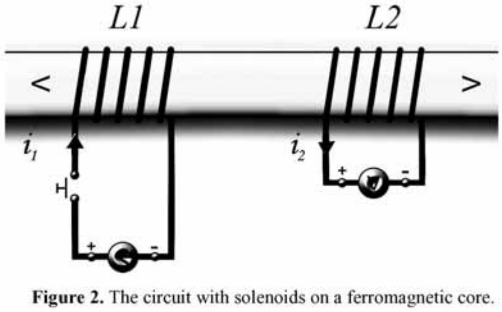

Figure 2. The circuit with solenoids on a ferromagnetic core.

When we put such a structure to the changeable electromagnetic field, according to the Faraday and Maxwell laws [1, 2], the electromotive force will be induced in solenoids. In other words, the electromagnetic energy will be changed to electrical energy. What is more, when we use the ferromagnetic core yarn, the magnetic component of the electromagnetic field will be dumped as a result of magnetising the steel yarn. This is the first solution for such a dumping problem of a magnetic component of the electromagnetic field in the textile industry, because barrier fabrics or nonwovens nowadays produced work on the basis of the rule of the Faraday Cage and induced Foucault Currents [3, 4]. The use of fancy bunch yarns built with copper as an effect yarn and steel yarn (Bekinox) as a core yarn will permit to create a microcircuit with solenoids arranged in row on a ferromagnetic core. This idea was constructed on the basis of many years of experience of the author of this project in the field of investigations on fancy yarns [5, 6]. These types of yarns and fabrics with these yarns (as a weft) were produced at The Institute of Textile Architecture, Faculty of Materials Technology and Textile Design, Technical University of Lodz in Poland according to the project granted by the Polish Government (Fig.3).

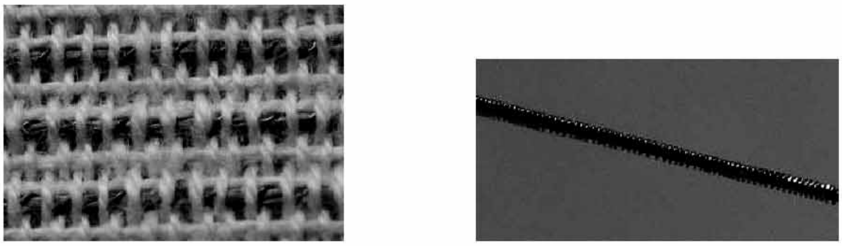

Figure 3. Fabric with circuit of copper solenoids on the steel core yarn produced in The Technical University of Lodz (Own research).

This idea was patented in 2009 (P – 387580). The first trials with the changeable electromagnetic fields were done. The production of such types of yarns is easily possible on a hollow twisting machine (HoGent School) on the basis of raw materials which are easy to access (Bekaert). The production of the fabric was done especially on a shuttle loom to achieve a continuous circuit with solenoids. The current induced in the copper yarn can be transferred to the ground or can be changed to heat. To improve the comfort of use of such a fabric, this type of yarn was introduced as an every third weft. The basic weft was cotton.

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NATO ASI "Defense Related Intelligent Textiles and Clothing
for Ballistic and NBC (Nuclear, Biological, Chemical) Protection

ADVANCED NBC-PROTECTION SYSTEM (ANBCP-S)

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Key Words: ventilated full coverage nbc-protective system, aircrew, immersion protection, micro-climatisation

1. POSTER ABSTRACT

The ANBCP System is a multi-national co-operative program in order to develop fully integrated NBC Protection for aircrew in all kinds of military aircraft ranging from fast jet to various helicopter and transport fleets. The task was to develop a completely new head-to-toe protective system. Included in this new system are chemical and biological protection as well as physiological cooling and cold water immersion protection. The first system to be fielded is a fighter suit known as the AFP (ABC-Schutzausstattung Fliegendes Personal) Jet.

Autoflug GmbH has the system responsibility for the new NBC-Protective System. The project work is shared by companies from the USA, Canada and Germany. The NBC-Protection system consists of the one-piece full body suit LASA, meaning "luftgekühlter ABC-Schutzanzug" (English translation: "air cooled NBC-protection suit"), the FAS ventilated helmet, "Fliegerhelm mit ABC-Schutz" (English translation: "Flight Helmet with NBC Protection"), the filter blower unit and the corresponding survival vest. It protects the user not only against heat, flash fire, cold water immersion, wind, as well as against windblast and the effects of high altitude, but also guards the operator against NBC hazards. The system works with filtered air, which is vented through the suit and helmet, to create a micro climate close to the body. Since it is simple to don and doff its fewer subsystems, the system offers high comfort to the wearer over an extended time.

The decontamination of the system has been demonstrated numerous times during different NATO exercises and the system has fulfilled all NATO-standardized CCA-procedures.

A SNAPSHOT OF SMART TEXTILES IN MILITARY APPLICATIONS

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Key Words: smart textiles, military application, high technology market, personal protective equipment

POSTER ABSTRACT

It clearly takes an effort to find out about available smart textile products on the market now and on a short term perspective. Therefore, the transparency in the market of smart textiles for military applications is obviously low. A survey concerning the current status of smart textiles within the military sector was conducted. Various suppliers of military equipment and clothing were asked for their input. The poster presents the primary results of this survey.

The information shown shall not state what the latest developments in military smart textiles are but wants to communicate what is available on the market until today and shall give users as well as suppliers of smart textiles an insight into the upcoming developments within the market.

The results shown were accomplished within a PhD research in the scope of the European project SYSTEX - Coordination Action for Enhancing the Breakthrough of Intelligent Textile Systems (e-textiles and wearable Microsystems; Funding agreement No. FP7-ICT-2007.3.6-224386).

Even though some smart textile systems are already introduced to various market areas, it is unknown why the progress regarding further developments is still slow. Finding out about reasons why smart textile systems do not succeed on the market is the initial aim in the scope of the research accomplished.

BALLISTIC PROTECTION FOR PERSONAL BODY ARMOUR AGAINST FRAGMENTS AND BULLETS

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Key Words: ballistic protection, bullet, fragment, NIJ STD 0101.03 and NIJ STD 0101.04, STANAG 2920

1. INTRODUCTION

The company BOROVO – GUMITRADE d.o.o. Vukovar produces a variety of soft ballistic protective devices (vests, suits) which are tested by an independent ballistic laboratory BESCHUSSAMT Mellrichstadt, Germany, according to norms which are accepted in many countries: US – standard NIJ STD 0101.03 and NIJ STD 0101.04.
There are internationally known norms for testing and classifying of protective body armour, which specify six levels of ballistic danger respectively protection, from which four are sorts of soft protection (body armour and similar), and two for those with an additional hard ballistic protective plate. The norm admits trauma – effect in the value of 44 mm height, without regard on hidden or outer vest damage. The value of volume pressed in plastic basic is not defined.
The norm STANAG 2920 defines the level of protection against fragments with the speed v50, which means the speed which blocks 50% fragments with standard shape and mass.

2. TYPE OF PERSONAL BODY ARMOUR

We produce many types of body armour purpose – protection from fragments from exploded missiles, grenades, rejected missiles and physical shoots primarily for clearing of mines and for the protection against bullets.

2.1. Protective body armour against fragments /type B – 1/

Purpose:
Protective body armour B -1 to protect from fragments. This type enables comfortable wearing with movements during working, moving and using of military techniques, fire-arms and vehicles (e.g. for the tasks of mechanized earthy military troops).

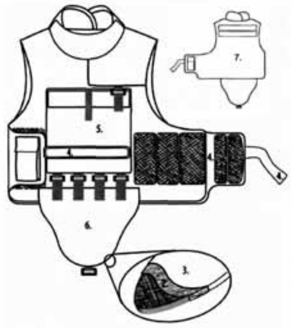
Composition:
The shape and construction are adapted for the protection of the upper part of the body, shoulders and neck, and additionally for genitals protection. The basic protection consists of frontal and beck sides jointed in the shoulder area and in the lateral area with elastic joints with overlapping in combination with Velcro tape. It enables easy adaption to the body shape and constitution. It is easy to dress and undress. The two - part collar is with overlapping and the frontal part is secured with an additional protective part. A ballistic plate is added in a pocket on the front side of the vest to increase the level of protection.

Material:
The vest is made out of textile materials. The basic ballistic protective package is made out of a certain number of complete layers /aramide textil Teijin Twaron (Akzo) or Kevlar (Du Pont), according to the given protection level. For the maximal increment of protective characteristics, the durability of the protective package is protected by a hydrophobic textile cover against moisture, perspiration and light. For additional buttoning and fixing there are buckles for band connections.
The outer cover and other parts are adapted for heavier wearing conditions. The back surface is visible marked. The outer look, colours, design, signs and similar are changeable according to the order.

Maintenance:
The parts for dressing, without the protective packages, can be washed in a machine or by hand. The ballistic protective packages and the additional protective part are cleaned with a wet textile.

The vest is tested by Beschussamt Mellrichstadt, Germany, in accordance with STANAG 2920.

Figure 1.



Composition of the anti-splinter vest:

1-Protection package (aramide PPTA material)
2-Cover for the protection package (hydrophobic)
3-Outer material of the vest (hydrophobic)
4-Bur band
5-Pocket
6-Genitals defender
7-Back part

We produce many types of Protective body armour against bullets such as:
B-2 - fighting protective vest with ballistic protection for genitals.
B-4 - for protection in conditions of higher risk from firearms. Comfortable for wearing even with intensive moving, working, during personal and vehicle armament (e.g. for demanding tasks for intervention of police brigades or security firms).
B-5 - for protection in higher risk conditions against firearms attack, it is made for the hidden wearing on underwear or shirt. It protects the upper part of the body with a big protective area.
B-6A - protective ballistic body armour for outer wearing. The ballistic soft protection of the vest is a protective package made out of multiple textile layers which are made of special polyaramidic filaments and which is protected against atmospheric influences with polyester textile which is impregnated with a silicon emulsion. The package is placed in the outer cover (the carrier of the ballistic package). The vest's outer cover is made out of textile Cordura 1500 which is waterproof, but air and water steam can pass through. It can be made according to the wishes of the buyer (white olive, blue, black, green-brown, camouflage etc.). The inside part of the outer cover is a combination of three components: Ve-Me net, thermotex Outlast, and thermotex protection. The ballistic hard protection is made out of two ballistic protective

layers /25 cm x 30 cm/, made from the combination of ceramic layers with ballistic protective textile. With the combination of hard with soft protection the total level is increased on III or IV according to NIJ 0101.04.
B-7, B-9, B-12 S are also protective ballistic body armours , which differ in some details / buckles, pockets, tags /, according to the degree of protection, patterns and color of the outer cover.

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NBC ISOLATION PROTECTIVE EQUIPMENT (PROTECTIVE SUITS, FOOTWEAR AND COVERS)

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Key Words: NBC protective equipment, protective suits, footwear and covers

1. INTRODUCTION

BOROVO – GUMITRADE d.o.o. in Vukovar is a firm grown out of gradual uniting all production and turnover product activities of rubber made products and coated textiles, which are divided in three basic product groups which have a long tradition:
- transporting belts and various rubber-technical goods - around 60 years
- working, protecting, sport and civilian rubber footwear - around 75 years
- bullet protection - 25 years
- NBC protection - 20 years

Contemporary market needs, new top quality materials, high technical level of international recognized technical standards are making the firm to orientate in the direction of contemporary ballistic and NBC protection. New developments are bullet protection for military and civil armed forces, NBC protective footwear and suits for military use.

1.1 Basic materials

For the production of personal NBC protection a combination of textile (PES) and rubber bromo-butyl rubber (BIIR) is used. They are resistant to physical conditions (rupture, friction and higher temperature and similar), low inflammable (they are self-extinguishing), but the basic protective characteristic is impermeability for most NBC agents. Colour, texture and thickness of the protective layer and the combination of protective layers are changeable according to the needs. The protective products are simple and easy to decontaminate, and they are made for multiple usage.

2. TYPE OF NBC PROTECTIVE EQUIPMENT

2.1. OZI M-2 Isolation protective suit

Purpose:
Device for military use, for NBC protection in conditions which need the complete protection of people by isolation from a radiated atmosphere. A protective suit is anticipated for multiple use in contaminated conditions, after preliminary decontamination. It has a wide range of applications, from control and rescue tasks in industry and mine, fire brigades and special rescue brigades, to special police and army forces.

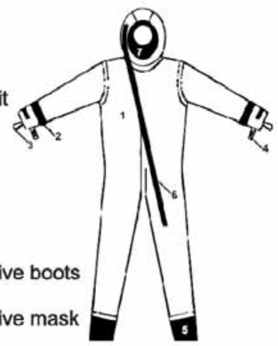
Composition:
The basic protective part is a one part suit with a hood. Opening for a face, sleeves and puttes' endings are made so that they can be well joined with a protective mask, elastic protective gloves and protective boots. The front side opening for dressing is hermetically closed and

does not let the gases go inside the suit, till 0.8 bar. All joints are sewed; joints are additionally strengthened and cannot let gases inside the suit. The inner band is fixed in the waist area.

OZI M-2

Composition of isolating protective suit

1 - Basic protective part of the suit
2 - Elastic gasket for joint with protective glove
3 - Loop for joint of end of sleeve
4 - Belt with velcro band
5 - Elastic gasket for joint with protective boots
6 - Zip for dressing´s opening
7 - Elastic gasket for joint with protective mask



2.2. Protective boots

Purpose:
Device for personal multiple foot protection against NBC substances (nuclear, biological and chemical protection) and against light-warmth radiation. The construction of the boots is adapted for combination with an isolating protective suit.

Composition:

- Lining-coated cotton material
- Upper: Face, reinforcement, counter, ribbons-rubber
- Lower parts: Insole-coated cotton material, fulfilling, designed sole, heel and strengthening in heel's part-rubber.

All joints are vulcanized and completely sealed. Boots are manually composed, vulcanized and individually tested in a waterproof test.

CZ M-1

Composition of protective boots

1 - Face
2 - Lining
3 - Strengthening
4 - Counter
5 - Ribbon
6 - Gasket for sealing a joint between the boots and a protective suit
7 - Indicating ribbon
8 - Sole
9 - Heel

2.3. Protective covers for military footwear

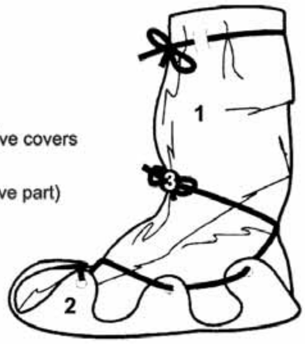
Purpose:
Device for personal protection in military applications, for soldier protection and lower part of foot, against NBC (nuclear, biological, chemical protection) for single use in contaminated conditions and multiple use in normal conditions. They are being worn over footwear. Low weight and small dimensions enables them to be permanently preventive in the complete of personal protection.

Composition:
The upper part is made from rubbered linen connected with vulcanization on rotational press. The sole is rubbered linen. Bands for bonding the sole and upper ending are made out of rubbered linen. Covers are hand made and joints are vulcanized on rotational press. The joint of the basic protective part of the cover and the sole is vulcanized in a press for footwear production.

NZ M-1

Composition of protective covers

1 - Face (basic protective part)
2 - Sole
3 - Band for fixing



The durability of the constructive materials of the protective suit, footwear and cover against chemical war substances is tested by independent laboratories: „EUROINSPEKT-EUROTEXTIL D.O.O." Zagreb, Croatia; „LABOR SPIEZ"- Switzerland; „TNO PRINS MAURITS LABORATORY" – The Netherlands. NBC Isolation Protective suit is currently waiting for official confirmation from „TNO PRINS MAURITS LABORATORY"- The Netherlands.

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"Weapons of mass destruction" (nuclear-chemical-biological weapons and toxical).

REAL-TIME INNOVATIVE IMAGE SYSTEM FOR REGISTRATION OF BALLISTIC BODY ARMOR DEFORMATION

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Key Words: body armor, ballistic packet, bullet impacting, cone deformation, high-speed camera.

1. INTRODUCTION

High-speed digital imaging is widely used to characterize fast events or processes in the military and civilian sciences. In the process of bullet stopping by ballistic body armor, the backside of the body armor is deformed to a certain degree. It causes rapid deflection of some place of chest and generates shock waves through the body, resulting in heavy internal injuries and occasionally death.

The optimization of the body armor structure concerning the deformation scale during bullet impacting, requires the analysis of the deformation from the initial penetration to the completed bullet stopping. It requires the use of a high-speed digital camera that shoots up to 1 million frames-per-second (fps). The recording time should be similar to time, which is needed for stopping the bullet by the ballistic body armor. In practice, it can be from a few μs to a few ms and depends on the bullet parameters, yarns row material and body armor structure. Accessible high-speed digital cameras can shoot more than 1 million fps but the number of frames in one scan can only be from 16 to 150 (e.g. [1]). It limits a precision analysis of the deformation during bullet impacting in the ballistic body armor.

We have developed a new innovative high-speed image system for the analysis of ballistic body armor deformation, which enables us to obtain successive images with the rate up to 1 million fps and the number of frames in one scan can be up to 100000.

2. CONFIGURATION OF THE SYSTEM

2.1 Outline of high-speed image system

A schematic diagram of our high-speed image system is illustrated in Figure 1. It is based on a successive registration of coordinates of marked generating line of cone deformation during impacting. The respective coordinates are measured by PSD (Position Sensitive Detector) array which is horizontally non-divided and linear, whereas vertically divided in numbers. Each PSD row element of the array is attached to the respective analog/digital signal processors.

In the presented system, the selected generating line of the cone deformation is lighted up by a linear flash light source. During penetration of the ballistic packet, the lighted line of the cone is "suspended" in space as a curve, which continuously changes its geometry. By the optical stage, this curve is projected on the photosensitive surface of the PSD sensor, where the coordinates are measured. Reconstruction of the cone deformation is possible by measuring the coordinates for some generating lines of cone deformation and applying numerical approximation algorithms, for instance based on the artificial neural networks. The coordinates measuring process for each selected generating line of cone deformation each time requires the use of a new ballistic packet. The measurement data are digitally processed and stored in real time.

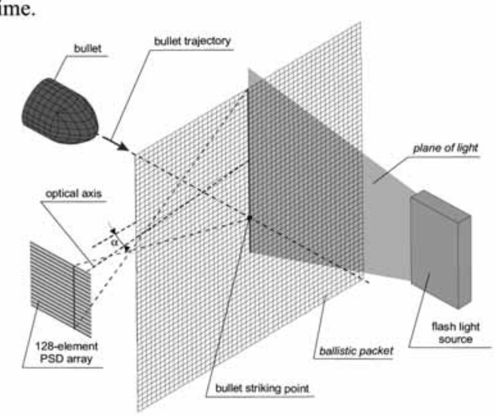

Figure 1. Schematic diagram of a high-speed image system

2.2 Example results

A high speed image system and anexample of time-course changes of thecone deformation during bullet impacting in the ballistic packet is presented in Figure 2. The ballistic packet was a compound of 16-layers of Twaron CT 709 aramid fabric. A Parabellum FMJ 9x19 bullet was used in the shooting.

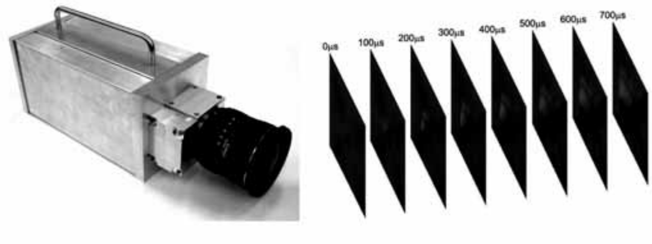

Figure 1. View of a high-speed image system and an example of the visualization of a body armor deformation

3. CONCLUSION

The presented high-speed digital image system allows the analysis of the deformation of body armor during bullet impacting. The numerical matrix of deformation allows different calculations like acceleration, velocity, max height and volume of the cone deformation in time, etc.

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NOVEL INTELLIGENT TEXTILE BASED ON SILICON FLEXIBLE SKINS

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Key Words: intelligent textiles, smart fabrics, electronic textiles, flexible skins

POSTER ABSTRACT

This paper shows the successful prototype development of a novel intelligent textile technology based on the integration of silicon flexible skins with regular textiles. Silicon flexible skins comprised of arrays of silicon islands integrated with boron-doped strain gauges and metal pads were successfully fabricated using micromachining techniques. The preliminary experiment showed excellent durability of the prototypes. Prototypes of intelligent textiles were developed by stitching the silicon flexible skins onto the surface of textiles. The strain experienced by the silicon islands was monitored in real-time using the integrated strain gauges when the prototypes were mechanically deformed.

TRANSPLANAR ABSORPTION OF LIQUIDS BY FABRICS

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Key Words: functional textiles, mass-transfer, water absorption.

1. INTRODUCTION

A considerable part of technical textiles is used in articles for defense against different harmful and danger actions: as barrier clothing for different fields of application; as building textiles (noise-isolation, interior materials–absorbers of harmful evaporations in inhabited and public buildings), medical textiles, etc. In view of these applications, it is important to define the influence of the raw composition and structure of textile fabrics and their capillary-porous structure on mass and heat-exchange processes.
A rather new direction in the creation of innovative functional textile structures is the combination of textiles with different physical properties in one package of a "sandwich" type. This widely enables to vary the properties of textile composites and packages and to control mass-exchange processes.
Aims of this investigation are the study of textile structure and the definition of water absorption and the transfer through initial single-layer textiles constants perpendicularly to plane textiles. This work is the first from a complex investigation of textile absorption properties: water, heat, dust, UV and EM-radiation. The final aim of the investigation is the creation of a database of textiles performance concerning the above mentioned properties. It will allow the elaboration of multifunctional multilayer textile structures with predicted properties.

2. MATERIALS AND METHOD OF INVESTIGATION

Research is carried out on the device SORP-3 (at the Textile Research Institute, Lodz, Poland) [1]. The Software ([2, 3]) allows to process the results of the measurements and to represent the results in the form of tables and graphic dependences.
Textile materials which differ by mode of production, fibrous compositions and structure have been chosen for investigation: ***Sa*** knitted fabric (PP–100%); ***Sp*** knitted fabric (Cotton–33%, PES–67%); ***El*** knitted fabric (Viscose–100%); ***Al*** knitted fabric (PP–40%, Cotton–60%); ***OST*** knitted fabric (PES–100%); ***Lu*** woven fabric (PES–100%); ***Ar*** woven fabric (PES–100%); ***KL*** knitted fabric (PA–60%, PE–40%).

3. RESULTS OF INVESTIGATION

Kinetic curves of the water absorption by individual textiles are shown in fig.1; curves of the absorption speed are shown in fig.2. Constants of water absorption of the investigated textiles are:
U_{max} – max water absorption, mg/cm^2;
V_{max} – max water absorption speed, mg/cm^2·s;
τ – constant, is equal to time that one needs to reduce V_{max} to "e";

t_0 – induction time (characterizes a delay of the absorption beginning);
t_a up to t_b – time characterizes a rectilinear site of the water absorption speed;
t_b – is time of achievement V_{max};
t_{max} – time of max sorption achievement.

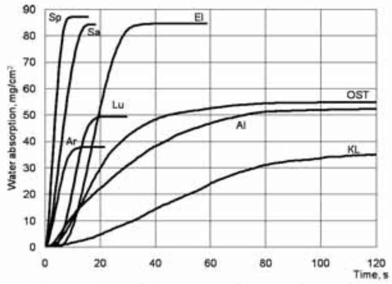

Figure 1. Kinetic curves of water absorption

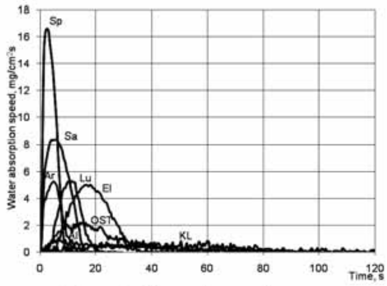

Figure 2. Absorption speed curves

Constants of water absorption of the investigated textiles are shown in table 1.

Table 1. Results of sorption constants for investigated fabrics

Sample code	U_{max}, mg/cm²	t_0, s	t_b, s	V_{max}, mg/cm²·s	$V_{30\text{-}70\%}$, mg/cm²·s	t_{max}, s	τ, s
Sa	84,1	0	9,0	8,8	8,1	~15	3,3
Sp	87,1	0	4,5	16,8	14,7	~10	6,2
El	84,6	7,5	22,0	5,3	4,8	~33	2,0
Al	52,7	3,0	68,5	1,5	0,45	~90	0,6
OST	55,5	5,0	24,5	4,5	3,6	~80	1,7
Lu	49,5	4,0	12,0	5,8	5,3	~20	2,1
Ar	34,7	0,5	6,0	6,1	5,2	~15	1,2
KL	35,4	15,5	64,0	1,8	0,6	~105	0,7

The analysis of the data shown in table 1 enables to divide the investigated textile materials into different groups: on size of water absorption (*Sp* > *El* > *Sa* >… etc.); on a parameter of the maximal absorption speed (*Sp* > *Sa* > *Ar* >… etc.); on time of impregnation (*Kl* > *Al* > *OST* > … etc.) and on capillarity (*Ar* > *Lu* > *KL* > … etc.).

4. CONCLUSION

The creation of a databank of water absorption constants of textiles will allow the prediction of properties of textile packages and composite materials.
The received experimental indices will be used for the elaboration of an analytical model of water absorption by single and multilayer textile materials.

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Wednesday 14th April 2010

Session chair : Prof. Dr. T. McLellan

9.30-10.45 **Natural fibers for soft ballistic protection and related test methods**
Prof. M. Pirlot, Royal Military Academy (RMA), Department of Weapon Systems & Ballistics, Belgium

11.15-12.30 **Innovative 3D textile structure for soft body armour protection**
Prof. F. Boussu, ENSAIT, GEMTEX Laboratory, France

16.00-17.15 **Fit issues in protective clothing**
Prof. H.A.M. Daanen, TNO Defence and Safety, The Netherlands

Work in progress on textiles for ballistic protection :

17.45-18.10 **Influence of woven fabric structure on its ballistic properties – experimental approach**
Mr. Zbigniew Stempien, Technical University of Lodz, Department of Clothing and Textronics, Poland

18.10-18.35 **High-speed tensile testing of filament yarns for composites under impact load**
Dipl.-Ing. Jan Hausding, Technical University of Dresden, Institute of Textile Machinery and High Performance Material Technology, Germany

18.35-19.00 **Behaviour of warp interlocks structures under an IEDs attack, application with orthogonal and through-the-thickness interlocks**
Ms. Marie Lefebvre, ENSAIT, Department of Textiles, France

NATO ASI "Defense Related Intelligent Textiles and Clothing
for Ballistic and NBC (Nuclear, Biological, Chemical) Protection

NATURAL FIBERS FOR SOFT BALLISTIC PROTECTION AND RELATED TEST METHODS

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Key Words: ballistic protection, FSP, V_{50} , deformation velocity.

1. INTRODUCTION

The first part of this contribution deals with the use of natural fibers in ballistic protections. Based on this practical example the test methods used for the evaluation of the ballistic resistance (protection) are discussed in the second part.
The third part emphasizes two original test methods used to provide more insight in the perforation phenomenon.

2. NATURAL FIBERS

Natural fibers are very attractive in the light of the growing environmental awareness because they are renewable, biodegradable and low cost resources. Investigation on the ballistic performance offered by natural fibers was initiated at ABAL. Fragment Simulating Projectiles (FSP) have impacted flax fabrics at different velocities in order to assess the ballistic limit velocity, or V_{50}. Natural fibers were dry or restrained by a polymeric matrix. Different areal densities and weaving structures have been tested [1].

3. V_{50} VS. "NO PASS" CRITERION

Beside the relevance of the V_{50} value related to the FSP solicitation it is demonstrated that this concept is also valid, and even more pertinent than the "no pass" criterion, for the classical bullet protection.
The knowledge of the standard deviation on V_{50} (S V_{50}) combined with the latter allows a probabilistic approach which seems to be better adapted to deal with the stochastic behavior of the combination protection-aggressor. In some cases V_1 and V_{100} can be derived from the duo V_{50} and S V_{50}. For one particular combination "steel protection – bullet" the estimated V_1 and V_{100} were compared with the experimental values [2].

4. EXPERIMENTS

In most of the experimental research the projectile velocity measurement is limited to the impact velocity and the residual velocity. Details of how the energy is absorbed remain unknown. The main parameters to compare numerical results to experiments are residual velocity and maximum fabric deformation. If one wants to use numerical simulations to assess the penetration process, not only these two parameters should correspond, but also the simulation should describe the whole process correctly. So one needs a continuous measurement of the phenomenon to validate numerical results.

4.1 Doppler CW measurements

A technique, using CW (continuous wave) radar, is being developed in order to obtain the continuous measurement of projectile velocity during ballistic impact. Based on the Doppler effect, and using Joint Time-Frequency Analysis, a velocity-time plot is obtained. From this curve displacement-time plots and force-time plots can be obtained.
A 6.5 mm diameter spherical projectile has been launched on one ply of plain weave aramid fabric at a velocity of 100 m/s. The velocity is obtained with a 26 GHz radar and a high-speed video camera. The projectile loses half of its velocity during the first 300 µs of the impact. During the next 1000 µs the projectile velocity continues to decrease, but much more smoothly [3].

4.2 Optical out of plane measurements

The Doppler approach can be combined with an optical method. For both flexible and rigid body armor, ABAL currently is in a position to determine the out-of-plane displacement - time curve by means of a contactless technique based on Digital Image Correlation. High-speed video image pairs are processed by appropriate software to provide this displacement with a high spatial and temporal resolution. Results with rigid armor are fairly reproducible whereas soft armor undergoes important influence from the boundary conditions induced by the clamping of the tested sample [4].

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INNOVATIVE 3D TEXTILE STRUCTURE FOR SOFT BODY ARMOUR PROTECTION

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Key Words: Textile Composite, High Performance Yarns, Personal Protection, Body armour, Warp Interlock fabrics.

1. INTRODUCTION

The actual needs for battlefield soldiers are to be protected from ballistic and CBRNE threats and also to be in permanent contact with the logistic support of the commander. Ballistic, CBRNE and tactical jacket are currently 3 different components, developed separately and worn on top of each other. One of the EPIDARM project's targets is to propose a personal protection demonstrator of the optimal system configuration in order to reduce the cost, the weight and improve the protection. The system approach developed for the EPIDARM program considers the protective system inside its environment (threat, wearer: generic soldier, task and climates). The latest emergent technologies in ballistic and CBRN protection, ergonomic effectiveness and financial cost are considered and help to select final solutions.

1.1 Body armour protection design

Armours can be designed to protect against a wide range of ballistic threats but, as the threat increases, the armour becomes heavier, stiffer and bulkier. Armour is good if it provides ballistic protection but also if it allows the wearer to operate easily a weapon system and to move quickly. Bullet proof vests are ranked according to their capability to defeat rounds. Soft body armour vests for law enforcement and civilian use consist of several layers of woven or UD fabrics made of para-aramid or polyethylene. They protect efficiently against handguns ammunitions (from Level I to Level III-A from NIJ Norm 0101.04) and also against fragments.

1.2 Textile material for ballistic protection

Generally, the main disadvantages encountered with ballistic structures are the adverse effects of crossover points of fabrics and laminates delamination [1] [2]. This becomes a significant factor when shooting multi-impact because the integrity of the structure is no longer maintained. It seems interesting to use multiple technologies by taking advantage of their strong points while combining 3D textile fabrics.
Different kinds of 3D weaving architecture can be chosen in order to take into account the tensile strength, the shear strength and the delaminating process according to the lifetime of different kinds of ballistic impact [3] [4].

1.3 Warp Interlock Fabrics

An important feature of the warp interlock fabric is the presence of yarns in the thickness direction. These help to maintain the cohesion of the structure during an impact and thus reduce the effects caused by delamination in the laminates. The interlock structures exhibit good impact resistance. With this type of reinforcement, improved damage tolerance (in ballistic terms) is expected, which may be helpful in case of multi-impact hits.
Thus, one of the proposed solutions to improve the ballistic protection and reduce the weight of body armour is to integrate 3D fibrous architectures, as warp interlock fabrics, at different specific locations calculated to absorb a calculated amount of energy.

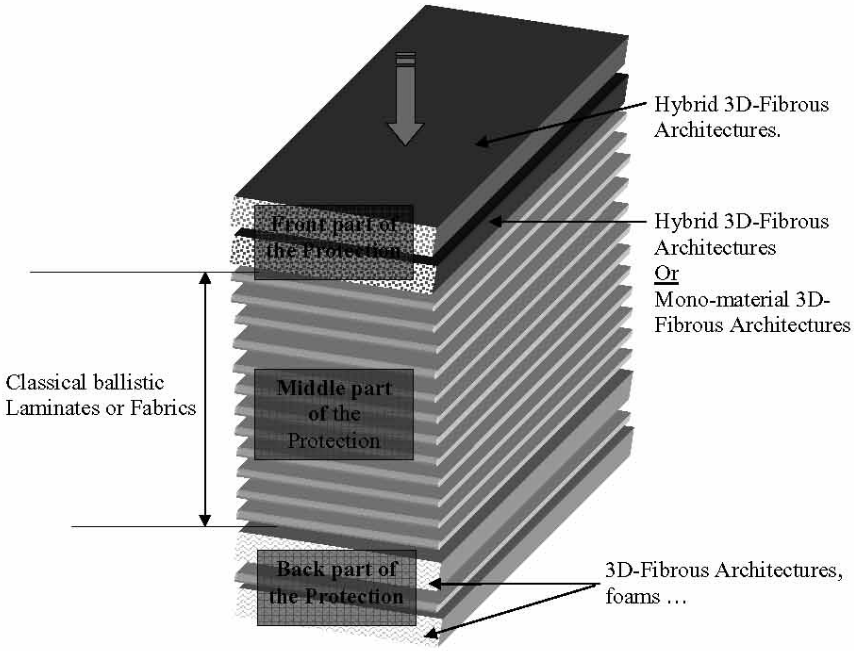

Figure 1. Global design of innovative solutions of ballistic protection

2. CONCLUSION

Ballistic tests have been performed on different configurations of textile material solutions. The main parameters have been identified and their potential effects on ballistic performances have been described. Interesting results are obtained when using different tows of high performance yarns located at the back face of the ballistic protection.

3. ACKNOWLEDGEMENTS
The authors would like to thank the European Defence Agency (EDA) and the OUVRY SAS Company to support financially all these research works.

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FIT ISSUES IN PROTECTIVE CLOTHING

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Key Words: clothing fit, garments, body dimensions

1. INTRODUCTION

Recent developments in clothing applications have led to a renewed interest in clothing fit. The increased application of garments as platforms for providing information exchange with the soldier serve as a good example. Controls, wiring and actuators integrated into such garments that are used to update the soldier with the newest information often require intimate contact with the skin for the system to function properly. An example of an actuator system is the navigation belt, in which the direction of travel is not visualized but is communicated via tactile stimulation with vibration elements, similar to those used in mobile phones. These actuators need a good contact with the skin to be perceived properly. A good fit is also required for personal cooling systems that need to fit tightly in order to cool the skin since air layers between skin and the garment are insulators and should be avoided. As such ensuring a good fit may be the key to the success of future garments.

2. CLOTHING FIT

2.1 Body dimensions

Ideally every product that humans wear, or use, should be designed according to the subjects' body dimensions. This holds true for clothing. Indeed recent databases of the body dimensions of the user population should be the starting point of clothing design. Such databases should be recent since human body dimensions are known to change considerably with time. Two international standards are available that describe how to measure these dimensions unambiguously: ISO 7250, focusing on technical designs, and ISO 8559 for clothing.

More recently, 3D-scanning systems entered the market from which one-dimensional data for clothing design can be deduced. Linear dimensions derived from 3D scans are very reproducible when markers are attached to the body prior to scanning [1]. The 3D information is useful for the design and evaluation of protective clothing. Subjects can be scanned with and without protective clothing and the 3D profiles can be superimposed to visualise fit (Fig. 1).

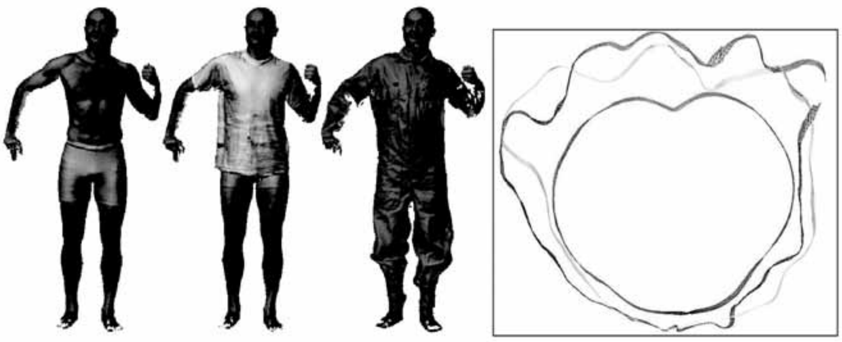

Figure 1. 3D-scan example of a subject seminude, with T-shirt and with coverall. The insert at the right side shows a transverse section at the chest level.

2.2 Sizing systems

Several sizing systems exist of which the traditional confection system based on chest circumference is the most common one. The size corresponds to 50% of the circumference, e.g. jacket size 52 for a chest circumference of 104 (102 to 106) cm. Generally, steps of 4 cm in circumference are assumed. However, the confection sizing system is only related to the circumference of the body and therefore provides a size set that does not accommodate human body variation. Sometimes this system is expanded to incorporate length size, e.g. size 53 means size 52 (chest circumference 102 to 106 cm) with extra length. Length and circumference body dimensions have a low correlation and can therefore be considered as almost independent. The NATO sizing system takes this into account since both length and circumference are included in the sizing system. Therefore, it is not surprising that this system showed the best sizing efficiency [2].

2.3 Fit mapping

When anthropometric data are available, the data should be matched with the product under design or evaluation. This analysis, also called fit mapping, indicates if the clothing sizes are accommodating the user population. Daanen and Reffeltrath [2] provide examples for fit mapping related to NATO sized products.

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INFLUENCE OF WOVEN FABRIC STRUCTURE ON ITS BALLISTIC PROPERTIES – EXPERIMENTAL APPROACH

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Key Words: body armor, woven fabric structure, tension wave propagation velocity, bullet stroking.

1. INTRODUCTION

The development of flat textile ballistic barriers and the improvement their effectiveness was mainly based on improving the strength of raw materials used for their production. However, the commonly used flat textile barriers are woven fabrics, in case of which geometrical structures may play an important role in the ballistic resistance of the product built of them. Depending on the geometrical structure of the woven fabric, defined by the so-called weave structural modules, the velocity of propagation of the tension wave was tested, as it was assumed that it can influence the amount of kinetic energy of the bullet absorbed during the stroke and the way of absorption.

2. WOVEN FABRIC STRUCTURE VERSUS WAVE PROPAGATION VELOCITY

An original measuring method for analyzing the tension wave propagation velocity was proposed [1, 2]. Taking into account the research results of the velocity of propagation of the tension wave and fabric classification with a module model, it was found out that two optimum fabric structures for ballistic barriers can be distinguished:

- in case of fabrics with stable structure, the ballistic panel should be executed from fabrics with plain weave and maximum warp and weft density. For such a fabric construction the propagation velocity of the tension wave is from 2 to 2.5 times smaller in relation to the tension wave velocity in yarn used to manufacture the fabric.
- in case of fabrics with unstable structure, the ballistic panel should be executed from fabrics without weaving points (glued non-interlaced structures). For such structures the propagation velocity of the tension wave is approximately the same as the tension wave velocity in yarn used to manufacture the fabric.

On that basis, a stand for forming glued non-interlaced structures was constructed. Taking into account the investigation into the influence of the weave structural modules of the fabric on the velocity of propagation of the tension wave, such a structure should be characterized by a maximum propagation velocity of the tension wave for the chosen raw material and density of threads in individual warps.

3. BALLISTIC TESTS

Both structures were made of para-aramid yarns type Twaron CT Microfilament 930 dtex/f1000. A comparable density of threads for both warps in the non-interlaced structure and the density of warp and weft in the plain-woven fabric were kept, so that the area densities of both structures remained similar. The tested variants consisted of the following layers:

- Variant 1 - ballistic packets consisting of layers of the non-interlaced structure,
- Variant 2 - ballistic packets consisting of layers of the plain-woven fabric,

- Variant 3 - ballistic packets consisting alternately of layers of the non-interlaced structure and plain-woven fabric.

In each variant the sample packets consisted of 6, 8, 10, 12, 16 and 24 layers. The dimensions of each sample were 30cm x 30 cm. After the ballistic packets were prepared as described above, tests were made of the deformation cone and absorbed kinetic energy of the bullet at the Laboratory of Ballistic Research. In the tests Parabellum FMJ 9x19 mm bullets of the impact speed (360±10) m/s were used. During testing, each sample was clamped in four edges. Based on the measurements results, ballistic characteristics of the packets were determined, establishing security limits resulting from the I (no shooting) and II (deformation depth) safety criterions of ballistic packets.

Analysis of the security limit according to criterion I, for packets in variants 1, 2 and 3 shows that all types of the packets can be used for ballistic barriers. The packet in variant 2, for which the security limit is ten layers, possesses the best properties. For the remaining two types of packets, packets consisting of 12 layers determine the security limit.

Analysis of the security limit according to safety criterion II it indicates that only packets in variant 1 and variant 3 fulfill the criterion for the adopted measuring conditions and boundary conditions. Analysis of the security limits resulting from not shooting through and maximum height of the deformation cone below 44 mm proves that for ballistic packets made of non-interlaced structures it is possible to simultaneously fulfill both criteria during the fire with much smaller area density, comparing to ballistic packets made of fabrics with plain weave. Thus, the hypothesis concerning the connection between the propagation velocity of the tension wave and the ballistic efficiency of the developed packets was positively verified.

4. CONCLUSIONS

- The propagation velocity of the tension wave along the warp and weft threads in classic woven fabrics depends on the geometrical structure parameters of these fabrics such as: weave, density of warp and weft threads. Depending on these parameters, it is from 2 to 5 times smaller than the propagation velocity of the tension weave in the thread of which the fabric is made.
- There are two optimum fabric structures that can be applied for the layers of a textile ballistic packet:
  - non-interlaced structure,
  - woven fabric with plain weave and maximum density of warp and weft threads.
- For ballistic packets made of non-interlaced structures SMS 4, both safety criteria are fulfilled during fire by a significantly smaller area density in relation to ballistic packets made of fabrics with plain weave.

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HIGH-SPEED TENSILE TESTING OF FILAMENT YARNS FOR COMPOSITES UNDER IMPACT LOAD

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Key Words: High-speed tensile test, multi-layer weft-knit, helmet, ballistic protection

1. INTRODUCTION

The application of complex structures made of composite materials which are subject to strict safety requirements necessitates the examination of short-time and energy-intensive loads resulting from impact or explosion. The tensile stresses thereby induced in the composite need to be transferred by the reinforcing fibers, which are subjected to extreme rates of loading and strain (with forces being applied within milli- or microseconds). The resulting large and sudden deformations require a high energy absorption capacity. An exact knowledge of the mechanical properties of the reinforcing fibers under high-speed loading is a prerequisite for the development of suitable dimensioning and calculating methods. Based on research regarding the development of textiles for ballistic protection used in helmets and cars, tests on the performance of filament yarns under high-speed loading are carried out. Resulting data can be used for a variety of applications, such as body armor, helmets, vehicles and buildings.

2. PROTECTIVE TEXTILES BASED ON MULTI-LAYER WEFT-KNITS

To be able to use existing and established manufacturing technologies, producers of hard ballistic components aim at developing new products with comparable performance while reducing production costs and improving reproducibility of the product's properties. To reach this aim, load-adapted multi-layer weft-knitted fabrics (MLW) were developed. They are used for cost-effective production of light-weight composites used in protective helmets and armored fender flares or other car parts (Fig. 1). Ballistic testing of laminates made of multi-layer weft-knitted fabrics shows an equal performance of the MLW compared to standard woven fabrics. Experiments with the MLW-based fender flare confirm a performance corresponding to the ballistic protection level B3/B4 [1]. The excellent drapability of especially developed MLW, which results in significant waste reduction during the manufacturing process, demonstrates the potential of MLW-based laminates for the production of high-quality protection helmets.

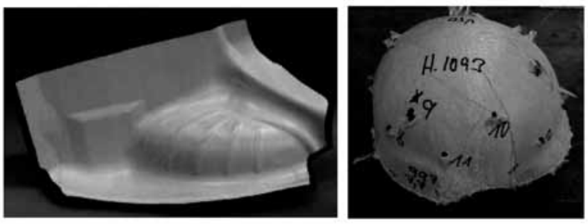

Figure 1. MLG-reinforced fender flare (left) and helmet after ballistic testing (right)

However, it will be necessary to improve the pressing tool as well as other details of the production process of the helmets, which is still optimized for woven fabrics, thus not delivering the best possible results with MLW.

3. HIGH-SPEED TENSILE TESTING OF FILAMENT YARNS

During the development of said components it became clear that the behavior of textile fibers and yarns which are used in composite materials under highly dynamic tensile loading has so far drawn only limited attention. However, it is known that the behavior under load depends on the rate of elongation and cannot be deduced from the tensile strength under static or quasi-static loading [2][3]. Experiments were conducted with different yarns on several high-speed tensile testing machines. These machines were originally developed for testing of metals and plastics. Specialized testing machines for yarns with the required rates of elongation are not available. The aim was to evaluate the suitability of the testing equipment for tensile testing of textile materials and to gain first results on the stress-strain behavior of filament yarns (see Fig. 2). It was possible to identify the relevant influencing factors for the measured variables as well as the interface between testing machine and specimen clamping. Displacement measurement during the 2 millisecond test could be realized very precisely with a high-speed camera. However, exact measurement of the applied force is difficult and cannot be carried out with the available measurement method of a load cell integrated in the fixed clamping mechanism, as can be seen from the oscillation in the stress-time diagram (Fig. 2). Optimization of the measuring method, determination of the mechanical properties of different yarns depending on the rate of loading and the development of simulation tools are subject of current and future research work.

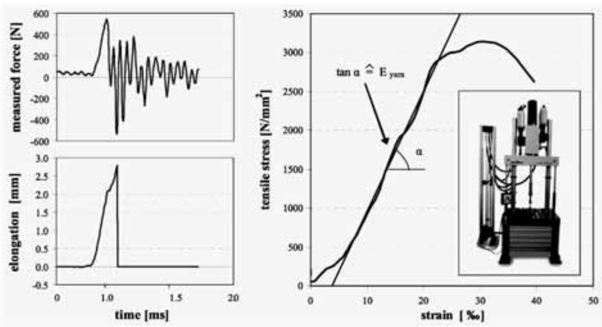

Figure 2. Behavior of aramide yarn (336 tex) under high-speed loading, rate of loading 20 m/s (testing equipment: Zwick HTS, Germany)

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BEHAVIOUR OF WARP INTERLOCKS STRUCTURES UNDER AN IEDS ATTACK, APPLICATION WITH ORTHOGONAL AND THROUGH-THE-THICKNESS INTERLOCKS

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Key Words: Warp interlocks fabrics structures, technical textiles, ballistic protection, Improvised Explosive Devices (IEDs)

1. INTRODUCTION

Textile structures are not only used for clothing, we also find them under different forms in areas of several applications such as aerospace, medical, construction and personal protection. Such textiles must have good mechanical properties to reach the requirements in their areas of application. The textile structures which are mostly used in technical application can be laminated, nonwovens, woven fabrics or knitted fabrics. In ballistic protection, we find mostly laminated or woven structures in soft protection or a combination of composite textile materials in hard protection. Such kinds of materials have to be efficient and resistant against impact but also against the blast effect. Currently, the two dimensional plain weave structures represent effective ballistic protection. See figure 1

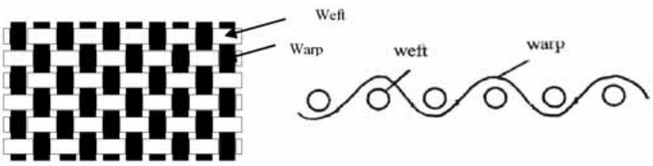

Figure 1. Illustration of a plain weave fabric

These conventional fabrics are sufficient as existing solutions but cannot help to reduce blunt trauma and weight of the body armour vest. That is why more and more textile structures are developed and especially the three dimensional structures as for instance the warp interlock fabrics. See also figure 2. Such structures are defined with a third yarn which goes inside the structure in the through the thickness direction. We could find three main types as layer to layer, through the thickness and orthogonal interlock. The interlock structures are presented as structures with good mechanical properties, a better performance through the thickness which can be adjusted by controlling the amount of z yarns. Moreover, the z yarns join the different layers into the fabric leading to more ballistic resistance and less delamination of the structure. See also [1], [2], [3], [4], [5].

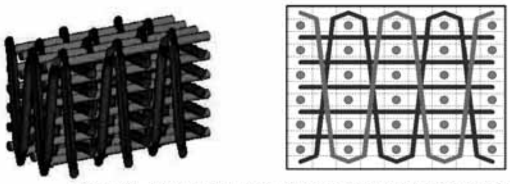

Figure 2. Illustration of an orthogonal interlock fabric [6]

This study focuses on the use of two warp interlock structures, especially orthogonal interlock and through the thickness structure, and tries to define the impact limit velocity and the energy absorption behaviour when a high speed fragment impacts the structure. The high speed fragment is used in order to simulate an IED (Improvised Explosive Devices) attack. They consist in an explosive charge with a layer of fragments on one or several faces. The detonation of the explosive accelerates the fragments to high velocities. The references [7], [8] and [9] give an overview of this type of IED threats.
Moreover, in order to understand the results, a comparison has been made with two dimensional plain woven structures at the same impact condition.
To conclude, the results are encouraging for the given structure. They allow us to understand the behaviour of these interlocks at high speed impact. Also we realize that many parameters influence their behaviour such as the bullet velocity and the kind of impact.

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Thursday 15th April 2010

Session chair : Prof. H.A.M. Daanen

9.30-10.45 **Options for managing thermal strain while wearing protective clothing**
Dr. T. McLellan, DRDC Toronto, Canada

11.15-12.30 **Influence of water on heat protection and analysis of steam burn formation in heat protective clothing**
Dr. R. Rossi, EMPA, Department of Protection and Physiology, Switzerland

16.00-17.15 **Nanomaterials for personal protection**
Prof. S.S. Ramkumar, Texas Tech University, USA

Work in progress on textiles for personal protection :

17.45-18.10 **Thermal protective performance and evaluation for protective clothing – Analysing thermal stored energy and effect on skin burn injury**
Prof. Guowen Song, University of Alberta, Department of Human Ecology, Canada

18.10-18.35 **The use of multirapier technology for woven 3D-fabrics**
Ir. Geert Declercq, University College Ghent, Department of Textiles, Belgium

18.35-19.00 **Native cotton fiber resistance to chemicals and cellulose solvents**
Dr. Adkhamjon Paiziev, Institute of Electronics Uzbek Academy of Science, Department of Applied Physics, Uzbekistan

OPTIONS FOR MANAGING THERMAL STRAIN WHILE WEARING PROTECTIVE CLOTHING

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Key Words: uncompensable heat stress, work and rest schedules, active cooling, dress state transitions

1. INTRODUCTION

Requirements for the military to wear protective clothing, such as fragmentation vests alone or in combination with biological and chemical ensembles, and carrying heavy loads during exposure to hot environments can quickly lead to conditions of uncompensable heat stress (UHS) where core temperatures can increase to dangerously high levels. One option to extend exposure times during UHS conditions is to slow the rate of increase in body heat storage with various intervention strategies.

2. METHODS

Studies involve monitoring rectal (T_{re}) and skin temperatures, heart rate and metabolic heat production while subjects walk on treadmills in various environmental conditions (30-40°C, 15-65% relative humidity). Subjects are dressed in various protective ensembles (NATO Dress States 0 through 4+Mask, firefighting protective clothing) and continue to the point of exhaustion or until an ethical ceiling for T_{re} of 40.0°C or 95% of maximal heart rate is reached. In one study with firefighters hand and forearm immersion in 18°C water was applied during rehabilitation periods of 20 minutes between 50-min work sessions.

3. RESULTS

The implementation of work and rest schedules is designed to slow the rate of heat production and, therefore, the rate of increase in core temperature. For work and rest guidelines to be most effective, however, some degree of cooling should occur during the rest period such that body temperature is lower at the beginning of the next work bout. In very dry desert environments the low vapour pressure still permits cooling during rest periods even when protective clothing is worn [1,2]. In more humid and tropical conditions, however, the vapour pressure of the ambient environment together with the thermal resistance of the protective clothing may create continued body heat storage even while at rest [2]. Under these situations, the implementation of work and rest schedules may not be the most prudent strategy. Work and rest schedules also do not typically accommodate the elevation in core temperature that results from prior activity especially when transitioning from a low to a high dress state [3]. Thus options in protective clothing design with the use of zippered vents may assist with slowing the rate of increase in body temperature during scenarios that permit the use of a low dress state prior to the transition to higher levels of protection [3]. The provision of continuous active cooling may not be feasible during work periods. However, commanders should be proactive during the rest periods and consider the use of active cooling strategies, such as hand and forearm immersion, to lower core temperatures prior to initiating the subsequent work periods [4-6].

4. CONCLUSIONS

In certain environmental conditions implementing passive rest periods while wearing protective clothing may actually decrease the total work accomplished while encapsulated. Commanders should consider clothing designs that minimize the heat strain in low Dress States prior to transitioning to high Dress States. Further, the use of active cooling strategies during rest periods will increase exposure times and work productivity dramatically compared with the implementation of only passive rest.

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NATO ASI "Defense Related Intelligent Textiles and Clothing
for Ballistic and NBC (Nuclear, Biological, Chemical) Protection

INFLUENCE OF WATER ON HEAT PROTECTION AND ANALYSIS OF STEAM BURN FORMATION IN HEAT PROTECTIVE CLOTHING

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Key Words: heat protection, water vapour transfer, moisture transport, steam

1. INTRODUCTION

The influence of humidity on heat protection of protective clothing assemblies was already analyzed several times [1-4] with sometimes contradictory results as the presence of moisture alters several parameters of the fabrics like the thermal conductivity or the heat capacity. Depending on the intensity of the heat flux, moisture in the layers may have a positive or a negative influence. Very few studies analyzed the impact of hot steam on multilayer assemblies [5, 6]. This paper gives a review of the different studies analyzing the impact of humidity on heat protection and analyzes the transport of liquid and vaporous moisture in multilayer protective clothing combinations. The dynamical moisture movements within protective clothing layers when exposed to low thermal radiation is shown by analysing the water content of the layers versus time with X-ray tomography.

2. MOISTURE TRANSPORT IN MULTILAYER PROTECTIVE CLOTHING

When working in a hot environment while wearing protective clothing, the body produces large amounts of liquid sweat. The uptake of sweat by the clothing layers, the evaporation rates, as well as the water vapour transport are mostly determined by the wicking properties and the water vapour resistances of the clothing layers. The moisture transfer can greatly vary depending on the set parameters: measurements at low temperatures and/or low relative humidity resulted in great differences in the skin and core temperature increases for different jacket types (PVC, Neoprene or leather vs. breathable materials) [7-9]. As soon as the temperature or the humidity of the environment approaches the conditions near the skin, the differences become smaller [10]. Griefahn et al. [11] and Rossi [12] did not find any significant differences between different types of protective clothing (breathable vs. non breathable) during exercises at higher temperatures.

3. ANALYSIS OF MOISTURE MOVEMENTS AND STEAM FORMATION

X-ray attenuation technique was already shown to be a valuable tool for the analysis of moisture distribution and movements in porous materials [13]. In the present study, moisture transfer within multilayer protective clothing assemblies at low thermal radiation was analysed using X-ray radiography. The radiography/tomography system was located in a large climatic chamber so that the heat flux of the infrared heater could not damage the X-ray system components. Evaporation was faster and took place at higher temperatures if the moisture was located in the outer layers of the clothing system. Moisture that evaporated in the outer layers of the clothing system was found to move inwards and condense in the inner layers and on the cap of the measurement cell.

4. CONCLUSION

The analysis of the influence of water on heat protection remains a very complex problem of coupled heat and mass transport. New analyses techniques help to understand the transfer of mass on the microscopic level and will help for the development of models to predict the risk of dry heat burns as well as steam burns and/or heat stress problems for workers and soldiers exposed to high thermal loads.

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NANOMATERIALS FOR PERSONAL PROTECTION

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Key Words: Nanofibers, Self-assembly, Electrospinning, Nanometaloxides, Protective textiles.

1. INTRODUCTION

Nanofibers have recently attracted considerable attention from researchers due to their structural characteristics. Electrospinning is a simple and widely used method of producing submicron-size nanofibers with diameters ranging from 100 to 500 nm [1, 2, 3]. Nanofiber webs, due to their pore size and large surface area, may act as adsorbent materials in filters, protective masks, and clothing [2].

1.1 Scope of the Problem

Although there is an abundant literature on the process-property relationships of electrospinning, limited information is available on nanofibers used as chemical protective liners. Scientists at the U.S. Army Research Development and Engineering Command, Natick Soldier Research, Development and Engineering Center in Natick, Massachusetts, have conducted research on electrospinning of nanofibers for chemical protection [4].

1.2 Aim of the Investigation

The use of nanometaloxide incorporated materials is providing new opportunities for detoxifying toxins [5]. These composite webs with increased filtration and reactive efficiencies could effectively destroy chemical threat agents when used as filtration and protection mediums. This paper aims to demonstrate the dispersion of nano magnesium oxides (MgO) in polyethylene oxide nanofiber webs, and subsequent evaluate the self-detoxifying capabilities of nanofibers.

2. MATERIALS & METHOD OF APPROACH

Functionalized nanofibers possess specific additives for incorporating special capabilities to nanofibers so that they can be used in a number of advanced applications [3, 6]. As the size of metaloxides reaches the nano level, surface reactivity increases due to high concentrations of reactive edges and defect sites. High surface reactivity coupled with high surface area enhances their utility for effective detoxification of chemical threat agents [3].

3. EXPERIMENTAL RESULTS & DISCUSSION

Results from the study (shown in Figures 1 and 2) clearly demonstrate that metaloxides can be embedded on the surface of polyethylene oxide (PEO) nanofiber webs by optimizing the electrospinning process parameters such as voltage, viscosity, distance between the spinning nozzle and the collector.

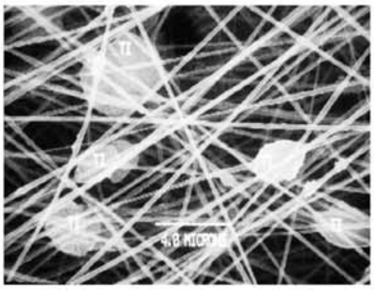

Figure 1. TEM image of a single polyethylene oxide nanofiber embedded with nano MgO at regular intervals [3.6].

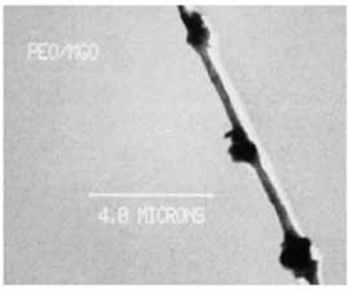

Figure 2. High-resolution TEM image of a single MgO nanoparticle embedded on the surface of a PEO nanofiber [3, 6].

4. CONCLUSION

The electrospinning process was capable of incorporating the nanoparticles on the surface of the self-assembled nanowebs. This is clearly evident from the regular pattern of the nodes in the transmission emission micrograph (Figure 1) and from the individual MgO nanoparticle embedded on the surface of a PEO nanofiber (Figure 2).

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THERMAL PROTECTIVE PERFORMANCE AND EVALUATION FOR PROTECTIVE CLOTHING – ANALYSING THERMAL STORED ENERGY AND EFFECT ON SKIN BURN INJURY

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Key Words: protective performance, stored thermal energy, thermal hazard, skin burn injury

1. INTRODUCTION

The performance of thermal protective clothing has been investigated extensively in recent years and a variety of thermal hazards with different levels of intensity, such as radiation, conduction and convection, were simulated [1, 2, 3, 4]. In these methods the test specimens were conditioned and exposed to a simulated thermal hazard and the heat flux transferred through the fabric or fabric systems was measured by a heat flux sensor. The heat flux registered by the sensor was used to predict skin burn injuries. The fundamental of these methods only provides basis for thermal insulation for clothing materials, not for clothing protection performance. When exposed to a thermal hazard, the clothing materials provide protection by slowing down the heat transport to human skin and can store thermal energy in fabric systems. The thermal energy contained in clothing materials during the exposure can discharge and contribute to skin burn injuries after the exposure is ceased [5]. The capacity of heat storage for fabric systems differs from their structure and physical properties.

In this study a stored energy approach was introduced. The approach is designed to capture the contribution to skin burn injury due to energy stored in the test specimens being released after the direct exposure had ended. The protection time predicted by the stored energy approach was compared with the traditional TPP/RPP approach which is similar to the ASTM F 1939, radiant heat resistance test. The difference of the discharge from energy restrained in the specimen with and without compression was examined. The study includes exposure intensity, test configuration (with and without spacer), and moisture effect. The Henriques Burn Integral (HBI) was adopted and programmed with a three layer skin model to predict the time required to achieve a 2nd degree skin burn injury. The results obtained demonstrate that the stored energy contained in different fabric systems varies and its effect on skin burn injury is different with exposure to different levels of thermal hazards. The involvement of moisture in the fabric system exhibits a different effect on thermal protective performance. The results suggest that the thermal stored energy contained in a multilayer fabric system is huge and contributes to skin burn injury, especially when compression occurs.

2. EXPERIMENTAL

This experiment utilizes the modified existing TPP and RPP tester to simulate different levels of thermal hazards. The software was modified to accommodate longer data collection times, and an insulating plate was used to compress the sample under test. The fabric systems were selected to represent existing clothing systems that cover from one layer, two layer (shell + moisture barrier) and typical multilayer systems (shell, moisture barrier, thermal liner). A stored energy approach procedure was developed; it includes exposure time, cooling period, compression and prediction of skin burn injury. The exposure time used just prior to obtaining a second degree burn result is considered to be a minimum value or the Minimum Exposure Time (MET) for the sample. If a second degree burn was not originally predicted during compression, then the procedure is performed and the exposure time is increased and the test is repeated using a new sample. This process is continued until a second degree burn is produced during compression [5]. The final exposure time which produced the second degree burn is considered to be the minimum value or the Minimum Exposure Time (MET).

3. RESULTS AND CONCLUSION

Table 1 Prediction time (seconds) for 2nd degree skin burn and different fabric systems

	One layer			two layer system			multilayer system		
Exposure (kW/m^2)	21	42	84	21	42	84	21	42	84
SE without compression	25	10	2	34	17	4	81	42	9
SE with compression	23	10	2	33	15	4	68	37	8
TPP/RPP approach	26.3	11.3	2.2	37.3	19.3	7.1	102.5	53.5	18.6
SE without compression (SP)	55	24	5	86	36	9	133	75	16
SE with compression (SP)	54	23	4	55	22	4	115	52	9
TPP/RPP approach (SP)	57.3	25.6	6.0	88.9	43.1	13.2	164.3	80.8	25.7

SE: stored energy approach, SP: with spacer (air gap of 6.3mm)

The data obtained demonstrate that multilayer fabric systems can store a significant amount of thermal energy and single layer fabrics show the minimum storage when exposed to heat as illustrated in Table 1. The energy contained in the fabric system can be released after the exposure and contributes to skin burn injury. The amount of energy discharged during the cooling period can be enhanced with the compression and the existing air gap in fabric systems. The proposed MET method counts for the transmitted energy during the exposure and the discharge from the energy contained in fabric systems after the exposure is ceased, and therefore it can be used to evaluate thermal protective performance under various conditions.

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USE OF MULTIRAPIER TECHNOLOGY FOR WOVEN 3-D FABRICS(*)

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Key Words: woven 3-D fabric, multirapier, face-to-face weaving

1. INTRODUCTION

There is a growing market demand for three-dimensional (3-D) fabrics as they have many applications. Many of the existing 3-D fabrics are being produced by technologies other than weaving. One reason could be that the desired characteristics of the structure can only be met with a knit, nonwoven, or braid. Another reason could be that it is not yet technologically or economically feasible to weave the desired structure.
Current production capacity of 3-D textiles limits expansion into other fields of application, leaving many opportunities untapped. At the '2nd World Conference on 3-D Fabrics and their Applications' (Greenville, April 2009), it was expressed that the need for 3-D fabrics exists, but production capacity is insufficient to cover the needs.

2. OPPORTUNITIES WITH MULTIRAPIER TECHNOLOGY

Probably the best alternative for producing 3-D woven structures is multirapier technology as applied in face-to-face weaving for velvet and carpet production. Multiple sheds can be formed and multiple wefts can be inserted simultaneously (Fig. 1), thereby forming different layers of fabrics (Fig. 2). This is a strict condition to produce 3-D fabrics. In addition these looms can produce fabrics with widths up to 5m, which is a major advantage in many markets. A large capacity of this type of looms is available in the textile industry. Matching this sizable capacity with the increasing demand for 3D-fabrics is the challenge to be met.

Figure 1. Triple rapier (Courtesy Van de Wiele)

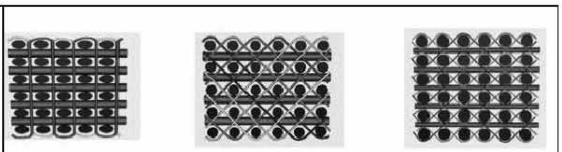

Figure 2. Woven 3-D fabrics with different warp binding constructions

Actually most of the woven 3-D fabrics are manufactured either with very sophisticated machines or with standard looms. Compared to both of these methods, converted face-to-face looms have significant advantages. The sophisticated technology is not available in adequate numbers and, moreover, using these machines in standard industrial conditions could be troublesome. Standard looms need to form a shed for every weft insertion and each weft needs a beat-up. These actions cause yarn damage, and with multiple wefts one on top of one another as shown in Fig.2, considerable yarn damage is observed. With multirapier looms the number of these actions is reduced, as two to three picks are inserted at the same time. Moreover production yield will be superior.

Loom modifications will be required due to fabric construction, as this is quite different from the construction of fabrics now actually produced on the looms. Moreover, the yarns made from raw materials often used in technical textiles such as aramids, glass, or carbon will be another challenge. Their stress-strain behaviour and abrasion on machine parts will require adaptations. This conversion of face-to-face looms into 3-D looms will be a milestone in the development of woven 3-D fabrics having major impact on the consumption of these fabrics. Having more 3-D fabrics available in adequate quantities will be advantageous for many companies and industries.

The use in composites is probably the best known application as aerospace and automotive industries have shown their interest on many occasions because they are successfully replacing metal constructions. But also agrotech, geotech, buildtech, medtech, protech, and other markets for technical textiles are consuming 3-D fabrics in increasing volumes.

Woven 3-D fabrics can be produced with different weaving densities in the top, middle, and bottom layers, facilitating water permeability and varying porosity top to bottom. These characteristics are required in geotextiles and filters. Sound absorbing wall protection is another application to be developed.

When it comes to ballistic fabrics, 3-D woven fabrics produced on multirapier machines show major advantages over standard fabrics. Because various layers can be woven in one step, stitching can be avoided. Warp ends can be divided into binding and filling warp ends. The filling ends and the weft yarns can both be positioned very straight in the fabric. Straight yarns contribute to improved fabric ballistic characteristics.

Using face-to-face looms creates the possibility to use different warp ends for the different layers making it possible to weave "sandwich fabrics" with layers showing great variation in characteristics. It is also possible to weave the various layers in different constructions. Hence warp density can be gradually varied within the limits of the reed, from top layer to bottom layer. This opens perspectives towards fabrics for noise protection, filter media, geotextiles…

Weaving with a very dense top and bottom layer, but with open intermediate layers, creates the possibility to fill the volume in between with protective materials. Examples include metal wires that can protect against radiation or the impact of projectiles and special yarns treated to protect against biological or nuclear impact. Because these stuffer yarns will make no direct contact with the body nor be exposed to sun radiation, they can be coated with materials that are not skin-proof or are unstable to UV-radiation. This opens possibilities for protective, but comfortable clothing. For the inner layers, fibres can be chosen with regard to user comfort and allow the fabric to remain "breathable". Consequently, these fabrics will have a major impact on the way protective clothing will be designed in the future.

3. CONCLUSION

The result of the conversion of face-to-face looms into 3-D looms will be an increase in the production capacity for woven 3-D fabrics, offering major opportunities for all partners.

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NATO ASI "Defense Related Intelligent Textiles and Clothing
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NATIVE COTTON FIBER RESISTANCE TO CHEMICALS AND CELLULOSE SOLVENTS

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Key Words: 4-cotton fiber, microstructure, cell wall, cellulose solvent

1. INTRODUCTION

According to the present conception [1] swelling and dissolution of cotton fibers is a process which depends on the morphological structure of the cotton cell wall and its developmental stages. A cotton fibre is a single cell, mainly made of cellulose microfibrils arranged in concentric walls. Accordingly, fibre development can be divided in five main growth stages, initiation, elongation, transition, development and maturation.
The purpose of this study was to develop an image analysis technique to quantify the morphological characteristics of convolutions in a single cotton fiber. The next focus of this paper is to study the swelling and dissolution of cotton fibres in order to clearly identify and separate the behaviour of the primary and the secondary walls in cuproammonium solvents. To this end, cotton fibres were collected at successive growth stages (2 weaks postanthesis (WPA)) , (4 WPA) and mature fibers.

2. MATERIALS AND METHODS

To visualize the outside morphological structure of the cotton fiber, a binocular optical microscope "Olympus" CH equipped with an ocular micrometer and Axioplan (Zeiss, Germany) with magnification 5x, 10x, 20x, 40x and 100x was used. Images were captured by a digital photo camera Canon PowerShot G6 (7.1 Mps) and transferred to a PC. Mature cotton fibers are arranged in parallel on the slide class and are covered by a slide. To reveal the microstructure of cotton cell walls and to examine the cotton wall layer resistivity to cellulose, the dissolution agent cuproamonium solution (Sweytserov reagent) has been prepared. An optical image of treated cotton fibers has been captured with different exposition times after treatment and observed dissolution dynamics of cotton cell walls. Cotton fibres (*Gossypium hirsutum* and *Gossypium barbadence*) taken at elongation stage 2 and 4 (WPA) were studied under the optical microscope.

3. EXPERIMENTAL RESULTS AND DISCUSSION

To clarify the developmental structural properties of cotton fibers, another method was used: suggestive dissolution cellulose layers under the impact of cellulose solvents [2]. It is shown that swelling and dissolution under the influence of a Schweitzer's reagent occurs mainly from inside the cotton fiber when the solvent penetrates to the inner cannel. At first, swelling and ballooning take place and then its dissolution. It is shown that for mature fibers (Fig.1a) mainly ballooning(Fig1b) before dissolution (Fig.1c) takes place. But for immature fibers heterogeneous swelling before dissolution can be observed. Cotton fiber varying at elongation stage (2WDA) do not show swelling and ballooning which is connected with the resistance of primary cell walls to dissolution in solvents because at this developmental stage, the fibers only have primary cell walls. These results show that the primary walls of cotton fibres is very resistant to dissolution in solvents. It is shown that S1 layer is very resistant to dissolution for all variety which may be connected with the high crystallinity of the S1 layer. This result shows that the balloons are indeed linked to the existence of a secondary wall layer under the primary wall. The remaining fragments were solid (most probably very crystalline) rodlike pieces, elongated in the fibre direction. This shows that the weak areas, most probably corresponding to less crystalline parts, were also oriented in the fibre direction. In case of immature fibers (2 WPA and 4WPA) the dissolution process occurred without ballooning and the fragments eventually dissolved totally. The outer layer dissolved more slowly. With the appearance of the S2 wall, an important phenomenon is observed. The inside of the balloons dissolves by fragmentation. A fraction of the cellulose chains inside the balloons is dissolving and balloons are growing due to the intake of solvent (osmotic pressure). After the total dissolution of the balloons, the unswollen sections and remainders of the primary wall will also dissolve. The sequence of dissolution is thus the following: first the inside of the fibre (S2 wall) by fragmentation, then the S1 wall, then the unswollen sections and remainders of the primary cell wall.

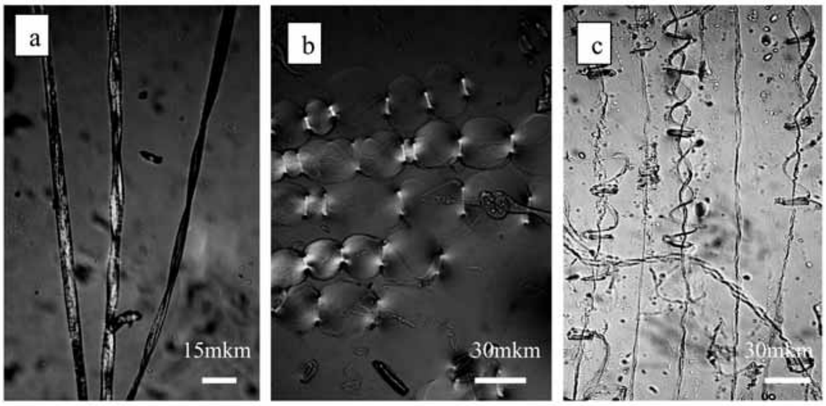

Figure 1. Difference dissolution stages of cotton fiber

4. CONCLUSION

It is shown that the dissolution of the primary wall is an inefficient process. The inside of the secondary wall dissolves by fragmentation, whereas the outside of the secondary wall swells. These data demonstrate the existence of age-dependent structural variations in the cell wall layers.

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Friday 16th April 2010

9.30-12.30 **Round Table Conference : Development of roadmap on Intelligent Textiles and Clothing for Ballistic and NBC Protection**
Discussions led by Prof. P. Kiekens, Dr. R. Rossi and Prof. A.M. Grancaric

Final evaluation and Discussion