EUROPEAN DEFENCE AGENCY

IFAST 2021

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Online edition

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Foreword

Smart Textiles are a new generation of materials and systems with key multifunctional properties (e.g. camouflage, moisture management, electronics integrated in textiles). These properties, together with the possibility of integrating the materials and systems in uniforms and platforms have drawn the attention of the defence stakeholders.

In this context, the European Defence Agency (EDA) has incorporated the Smart Textiles domain into the Strategy Research Agenda (SRA) of the CapTech Materials & Structures. In particular, one of the Technology Building Blocks (TBB), supporting the SRA, has been devoted to this area. Furthermore, other EDA CapTechs, such as the CapTech CBRN and Human Factors and the CapTech Ground Systems, have performed initiatives related to "Smart Textiles".

The EDA STILE project was designed to lay the foundation for a *European Multifunctional Smart Textile* focusing on defence and, specifically, tackling aspects of functionality, integration, comfort and lightweight.
Within the STILE project, the *International Forum on Advanced and digitalised Smart Textiles (IFAST)* was organized on 15 and 16 June 2021. Initially planned in Lisbon, EDA had to move the event to the online format, due to the covid-19 pandemic restrictions. However, all the initial features initially planned have been performed through the online platform.

IFAST was composed of an *Exhibition Centre,* from industries, academia and research organisations (RTO) presented their products, services and projects in the areas of smart, advanced and digitalised textiles, by means of 14 virtual booths, and a *Conference Area,* in which three keynote speeches were given from representatives of Portuguese Ministry of Defence and EU Institutions. In addition, the results of the STILE project were presented, and two panels were organised, moderated and introduced by renown experts in the field, namely:

- *Foresight on advanced and digitalised smart textiles in the European defence sector.*
- *Visualising a European dual use programme for multifunctional smart textiles.*

The IFAST event was followed by more than 160 participants coming from EU Institutions and all over the EDA Member States. IFAST disseminated an EDA success story (the STILE project) to the EU dual-use ecosystem, including industries, academia and RTO. In particular, the duality of smart textiles will bring this technology into the ongoing EU dual use policy debate, offering as enlightening example of dual use by design.

This book of abstracts includes the contributions to the IFAST Conference and Exhibition Centre. I trust the reader will appreciate the various aspects of the front-end smart textile technology and its potential contribution to the future EU dual-use ecosystem.

Jean-François RIPOCHE
Director Research, Technology & Innovation

IFAST 2021

International Forum on Advanced and digitalised Smart Textiles

15-16 June 2021, Online edition

STILE CONSORTIUM:

AITEX
Textile Research Institute

CITEVE
Technological Centre for the Textile and Clothing Industry of Portugal

INEGI
Institute of Science and Innovation in Mechanical and Industrial Engineering

IFAST PARTNERS:

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Advanced materials for emerging and disruptive technologies

MGEN Jorge Côrte-Real Andrade(*)
National R&T Director and Deputy Director of the Defence Resources Directorate (MoD)
(*)Email: jorge.andrade@defesa.pt

ABSTRACT

Advanced materials and their application are of the utmost importance to emerging and disruptive technologies. Defence organisations are deeply interested in supporting the development of emergent and disruptive technologies that are rooted in advanced materials, since they present unique and novel properties. Advanced materials combined with with Emerging and Disruptive Technologies (EDTs) have an enormous potential when manufacturing complex products that are multi-material, multiscale and multifunctional, and that have extreme performance characteristics, achieving improved productivity, quality, energy efficiency and environmental sustainability. Smart Textiles are a prime example of a new generation of materials and systems that offer various multifunctional properties with a large applicability in defence.

KEYNOTE SPEECH

Nowadays, multiple sources of innovation have accelerated the development of a wider range of technologies, particularly in regards to advanced materials, artificial intelligence, automation/robotics, optics and mechatronics, which expand the potential development of advanced materials and their application in emerging and disruptive technologies (EDT) to meet current and future challenging demands. These technologies involve research, development and manufacturing processes that can be used for multiple applications in the Defence and civil domains, as long as increased collaboration between Defence and civil entities is achieved.

The Portuguese Defence, Armed Forces, Academia and Industry have been very invested in advanced materials and EDTs. In 2018, we launched AuxDefence, the 1st World Conference on Advanced Materials for Defence, which started from a project with the same name, funded by the Portuguese Ministry of Defence. This year during the Portuguese Presidency of the EU, we hosted the EDA R&T conference about the "impact of disruptive technologies on Defence". Therefore, although these two topics are drawing the attention of many organizations, we felt that there is the need to address the linkage between EDTs and Advanced Materials, since they are becoming increasingly interconnected.

Even NATO considers Novel Materials and their Manufacturing as an EDT, as they present unique and innovative properties and are manufactured using innovative techniques drawn from nanotechnology up to synthetic biology. In order to improve readiness, protection and logistics support, this approach is focused on the soldier, in terms of human augmentation and protection, as well as on energy reduction, renewable sources and storage, additive manufacturing to enable field repair, manufacturing and deployment, and new materials, like graphene to enhance protection and corrosion resistance. On the EU side, a "Disruptive technology for defence means a technology inducing radical change, including an enhanced or completely new technology, inducing a paradigm shift in the concepts and conduct of defence affairs including by replacing existing defence technologies or rendering them obsolete". In this regard, one of the actions of the European Defence Fund (EDF) is focused on Materials and Components, including research related with advanced materials and structures applicable to defence. As such, on the European Defence Agency side, The Capability Technology Groups (CapTechs) already performed an analysis on the "overarching strategic research agenda" (OSRA) and the "technological building blocks" (TBB) roadmaps in order to identify projects that could be included in the future EDF work programmes in Emerging and Disruptive Technologies field. Themes as "Sensorisation and datafication", "Human-machine teaming and artificial intelligence", "Digitisation of matter" and "Human enhancement", which can be related to Smart Textiles, are part of this assessment. Furthermore, the technological building blocks (TBB) from CapTech Materials&Structures and CapTech Components established the path towards advanced materials research and

solutions based on smart textiles. Other EDA CapTechs, such as the CapTech CBRN and Human Factors and the CapTech Ground Systems, have also performed initiatives related to smart textiles.
These approaches reveal that technological advancements in the production and quality of materials — namely in terms of sustainability, programmable qualities and improved physical properties (with strengthened performance and reduced weight) — lead to new functionalities of materials that increase the scope of innovation. On the other hand, new challenges push for the development of new materials and approaches that could facilitate the emergence of Disruptive Technologies.

Currently, we are facing a strong geopolitical competition for materials (e.g. rare earth metals) used in areas that power the high-tech economy and are also critical for the manufacturing of climate economy products, which are subject to intense scrutiny by governments looking to ensure supplies as a matter of national security. Likewise, the production of some products, like semiconductors, is dependent on a very complex supply chain, which presents difficulties in responding to demand changes. At the same time, there is the need to comply with new requirements to improve the protection of human health and the environment, such as those included in the EU regulation on the Registration, Evaluation, Authorisation and Restriction of Chemicals (abbreviated as REACH). Nevertheless, this increasing pressure for environmental sustainability has created more opportunities for products to be remanufactured after their typical end-of-life. This approach is becoming more relevant and will also increase economic benefits both for manufacturers and consumers, leading to a truly circular economy.
Therefore, EDTs need to be based on sustainable materials, involving renewable energy sources into their processes in order to improve the protection of human health and the environment, and to provide a boost on circular economy. Although military needs tend to be more demanding on requirements regarding materials, the development of defence capabilities have to lead on this sustainability path.

Equally, advanced materials combined with EDTs have an enormous potential on the manufacturing of complex products that are multimaterial, multiscale and multifunctional, and that have extreme performance characteristics, achieving improved productivity, quality, energy efficiency and environmental sustainability. For instance, additive manufacturing has an enormous applicability in logistics. Having the capability and flexibility to produce spare parts anywhere, we believe this technology will have a key role in Defence, namely in operations as soon as some issues are solved, in particular on the consolidation of production standards. Furthermore, additive manufacturing, advanced composites, and 2D materials lead to the development of various lightweight products. Improved protection systems and platforms require reduced weight, not only in aerospace but also in soldier systems. A good example of Portugal's experience in this area is the already mentioned "AUXDEFENSE project on advanced materials for Individual protection", combining materials with strengthened performance and reduced weight in several applications that are already in use in operation theatres. Portugal's industry and academia have also achieved knowledge and competences on graphene and composite nanotube integration, which are being used to enhance not only mechanical performance, but also other properties. For instance, conductivity provides new functionalities, such as the ability to transform the component on its own sensor.
Other advanced products with complex intrinsic features require the use of macro-, meso-, micro- and nano-scale manufacturing processes. Moreover, the development of advanced materials and the increasing integration of multifunctionalities into a single product have pushed the wide adoption of innovative manufacturing processes, such as the combination of additive and subtractive manufacturing processes, as well as the use of electro-chemical and thermal-mechanical/optic manufacturing processes. This is the context of Smart Textiles, a new generation of materials and systems with various multifunctional properties with a large applicability in defence.

The project "Smart textiles in defence: looking at the soldiers of the future" (STILE), aims at integrating the functionalities of different smart textiles into a single smart combat system, which involves innovative processes such as the integration of electronic components in textiles, thermochromic formulations, ergonomic and fitting assessments, as well as simulation and evaluation of thermal protection and thermal signature. Portuguese organisations are already involved in the development of smart textiles. In fact, following the knowledge and experience achieved in the textile industry and in spite of the transfer of part of its production to Asian countries, the capacity for good quality production remains. Nevertheless, disruptive innovation is crucial to exploit opportunities and to gain competitive advantages such as those provided by the STILE project.
Being the result of several years of research and development, this project integrates key innovative functionalities to be used in real operational conditions, such as signature management, monitoring of environmental parameters

and CBR threats, flame retardancy, water and dirt repellence and anti-mosquito solution, physiological monitoring, temperature regulation and communication and wireless exchanging data. These multifunctionalities enable the monitoring of different parameters related to the state of the soldier.

Finally, the STILE project showcases EDA's relevant role in this area, namely through OB-funded studies that provide the state of the art in a specific area, and through technology demonstrators that strongly contribute to the Technological Building Blocks approach towards capability development. We believe that this is a fundamental approach to consolidating knowledge and producing the basis for new defence programmes. Additionally, STILE facilitated good collaboration opportunities amongst organisations of different nations, which will be relevant for the incoming challenges promoted by the EDF.

To conclude, I have to emphasise that it is a pleasure for us to participate in this event. Although it was not yet possible to organise it with physical presence, we hope that the next two days stimulate fruitful reflection and knowledge sharing, which can contribute to evolve these two increasingly interconnected domains: advanced materials and EDTs.

REFERENCES

1. EDA. *Food For Fhought Paper R&T Projects from OSRA in Support of EDF Planning in Emerging and Disruptive technologies,* EDA202009126/RTI, 2020
2. EDA. *Smart TextILEs in defence: looking at the soldiers of the future, Fact Sheet, 2020 Eggers W. D., Singh, S. K. The Public Innovator's Playbook: Nurturing bold ideas in government.* ISBN 978- 0979061110, Deloitte, 2009
3. FitzGerald, Sayler. *Creative Disruption: Technology, Strategy and the Future of the Global Defense Industry,* Center for a New American Security, 2014
4. NATO Science & Technology Organization. Science & Technology Trends 2020-2040. *Exploring the S&T Edge,* 2020
5. Probst, Frideres, Pedersen, Clarke, PwC Luxembourg. *Advanced Materials. The graphene revolution,* Ref. Ares(2015) 4649763, EU Commission, 2015
6. Tidd, Joe. *Digital technologies and disruptive innovation: from processors to platforms.* In: Digital disruptive innovation. Series on Technology Management, 36, ISBN 9781786347596, World Scientific, ix-xviii., 2019

KEYNOTE LECTURE
The European Defence Fund – a real boost for EU-wide defence R&D cooperation

Erno Vandeweert(*)
European Commission, Directorate-General for Defence Industry and Space
(*)Email: erno.vandeweert@ec.europa.eu

ABSTRACT

The European Defence Fund is a new funding programme launched on 1 January 2021, that will be running for 7 years with a budget close to 8 billion Euro. The Fund has, as its main objective, the fostering of the competitiveness, efficiency and innovation capacity of the European defence industry. It is designed as an industrial programme aiming at deepening cooperation between all defence R&D stakeholders. The main funding mechanism is based on grants supporting joint projects, following competitive calls for proposals.

Apart from supporting projects in the main military domains (air – ground – naval – space – cyber), the funding of materials and R&D components for military applications is also within the scope of the European Defence Fund. Up to 8% of the Fund's total budget will be used to fund projects on disruptive technologies for defence. The participation of innovative small and medium-sized enterprises will be particularly encouraged throughout this funding programme.

This talk presented an overview of the European Defence Fund and the next steps to expect in the coming months. Some examples from the Fund's precursor programmes (the Preparatory action on Defence research and the European Defence Industrial Development Programme) were given.

KEYNOTE LECTURE
Textiles in European Commission's policy priorities and initiatives

Marco Manfroni(*)
DG GROW Policy Officer
(*)Email: marco.manfroni@ec.europa.eu

INTRODUCTION

A swift and sustainable recovery will require new technologies, matching investments and innovation. The twin green and digital transitions will affect every part of our economy, society and industry. Textiles are not an exception.
In this regard, we have a large amount of research results in the EU.
However, there is still an existing gap between research/innovation and uptake into the market with little exchange of experts between the research and industry dimensions.
Moreover, SMEs face critical challenges in their structure and process for effective technology absorption & innovation.
Innovative and technological know-how is a driver for global competition and the EU needs to stay ahead.
In this context, I would like to mention some of the Commission's recent initiatives.

THE UPDATED INDUSTRIAL STRATEGY

In March last year, the Commission laid the foundations for an industrial strategy that would support the twin transitions to a green and digital economy. One day later, the World Health Organisation declared COVID-19 a pandemic.
The COVID-19 pandemic hit the European economy harder than any other economic shock in the history of the EU.
On 5 May 2021, a targeted update of the strategy was adopted, which focuses on what needs to be done and what lessons need to be learned following the outbreak of the COVID crisis.
14 industrial ecosystems have been analysed and compared. The analyses show that the impact of the crisis – and the prospects for recovery – vary significantly.
In the case of the textile ecosystem, with its interconnected and globally exposed value chains, we have seen disrupted supply chains and a sharp drop in consumer demand.

In this context, the updated Industrial Strategy focuses on three key areas:

- Strengthening single market resilience
- Dealing with the EU's strategic dependencies
- Accelerating the twin transitions

Openness to trade and investment is also a strength and source of growth and resilience for the EU, which is a major importer and exporter. Yet the pandemic has triggered wider awareness for the need to analyse and address strategic dependencies.
An initial analysis identified 137 products in sensitive ecosystems for which the EU is highly dependent, including some textile products (e.g. gloves and medical masks). Work on this area will continue.

EU STRATEGY FOR SUSTAINABLE TEXTILES

The pandemic has drastically affected the speed and scale of the transformation to support green and digital transitions.
The future strategy will set out a roadmap for the green transformation of the textile ecosystem.
It should propose a vision for a sustainable, digital and resilient ecosystem as well as its competitive development.

The building blocks of the strategic vision will emerge from the assessment of the gaps/bottlenecks and presentation of horizontal key actions on sustainable textiles (sustainable products, due diligence, among others). It will aim at supporting the industrial competitiveness, sustainability and innovation of the ecosystem, and at boosting the EU market for sustainable and circular textiles.
Finally, it will also aim at promoting the leadership that European companies have gained in several segments of the ecosystem such as technical textiles, smart textiles or high-end fashion.

FUNDING OPPORTUNITIES AND SKILLS

The textile ecosystem has been hit hard by the closure of retail outlets and in 2020 has seen a decrease in turnover by approximately 10% for textiles and 18% for clothes.
The Recovery and Resilience Facility is the key recovery instrument at the heart of NextGenerationEU, which will help the EU emerge stronger and more resilient from the current crisis. The Facility will provide an unprecedented 672.5 billion € worth of loans and grants in financial support for the crucial first years of the recovery.
It is up to the Member States to define their reform and investment priorities through the national recovery plans depending on the structure and the needs of their economies.
Hence, national authorities also play a critical role in making sure that the interests and opportunities for a strong recovery of the EU Industry (including the textile ecosystem), are taken into account in the national recovery plans.
Finally, some words on something very important for the textiles ecosystem: skills.
The new skills agenda envisages a Pact for Skills in the key 14 ecosystems identified by the Industrial Strategy, which includes textiles. The pact will focus on identifying challenges and targets, gathering partners, and identifying potential funding sources.
In view of this, the High Level roundtable on the Pact for skills for the textiles ecosystem took place on 16 March. A first follow up meeting regarding the roundtable took place on 7 May 2021 with the main partners, where some potential commitments were presented. A second meeting will take place on 21 June 2021 were more partners will be expected.

CONCLUSIONS

To conclude, I would like to stress the importance of projects such as STILE, which aim to bring research and industry together.
Only by ensuring technology and innovation uptake at a market and industrial level, we will we be able to strengthen the competitiveness of the EU Industry and ensure that researchers and industrial actors, such as SMEs, seize all the related opportunities.

INTRODUCTORY LECTURE
Foresight on advanced and digitalised smart textiles in the European defence sector

Mário C. Durão(*)
AFCEA Portugal
(*)Email: presidente.direcao@afcea.pt

ABSTRACT

Textiles are important components of much of the military equipment, being used for uniforms, tents, sails, parachutes, camouflage nets, dinghies, body armours, just to mention a few. Textiles have become a significant component of the defence industries with a growing impact in the military economy - one aspect that many times tends to be overlooked.
The evolution of the global geopolitical situation - with new actors and new threats to global security - imposes a more demanding strategic environment on society, also with greater uncertainty.
In responding to these new threats, the armed forces are faced with more complex missions and a much more undefined operating environment. Operations will essentially take place in urban environments on a continuous basis, twenty-four hours a day, in any weather condition and without rest, through continuous attacks distributed throughout all sectors and theatres of operations.

In this framework, the fighter of the future will be the centre of an integrated system of equipment aimed at increasing its effectiveness and improving its protection. Soldiers have to be given comfortable and lighter uniforms that still maximize their performances, and thus their physical strength. The essential requirements for contemporary and future military clothing are: durability, bullet resistance, camouflage, comfort, moisture management, temperature regulation, weather resistance, light weight, protective properties, flame resistance, chemical, biological and nuclear protection, UV protection, aesthetic appeal.
Smart textiles can meet these requirements. Smart textiles are defined and classified according to the standard. The applications, the drivers for the market, and the technologies of smart textiles are reviewed. The importance of the use of smart textiles in the defence sector is highlighted, describing their properties of greatest use in the military field.

Ongoing projects on the use of smart textiles are presented, involving several Portuguese entities in the Defence sector. In view of the countless and varied adversities to which the dismounted soldier is currently exposed, there is an urgent need to develop innovative technical and protective equipment to respond to the real needs that arise in the theatre of operations. In this way, advanced and digitalized smart textiles present several innovation opportunities for smarter, safer and faster military performance.
The general aims of future developments in smart textiles are presented. The principal aspects that represent significant needs in terms of research, development and standardization of smart textiles are also shown.

INTRODUCTORY LECTURE
Textile structure materials and their Dual Use perspectives in the European Industrial Ecosystem

Achilleas D. Stalios(*)
Health and Digital Executive Agency (HaDEA).Established by the European Commission.
Unit B3-Industry, Sector B3.2-Advanced Materials
(*)Email: Achilleas.Stalios@ec.europa.eu

ABSTRACT

In recent years, an increasing trend of smart textiles has been observed globally with an escalation in the use of optical fibres, metals, and various conductive polymers as multifunctional materials. The ability to detect and react to various physical stimuli such as mechanical, thermal, or chemical and electric sources -always in alignment with the demanded preference towards sustainable products- is a basic requirement for these types of materials. The industry has started to restructure and invest in manufacturing practices that specifically target sustainable products. Furthermore, their field of application has also been expanded to the defence sector, with the use of high-performance fibres such as carbon fibre, aramid, nylon or ultra-high molecular weight polyethylene.

INTRODUCTION

The textile market is segmented by raw materials, product and application types. Cotton led the market, followed by chemical-based textiles, wool, silk, minerals such as glass fibres, and other synthetic materials. Main textile products include natural fibres, polyester, nylon, polyethylene, polypropylene, aramid, and polyamide. Concerning applications, the fashion segment leads, followed by different areas of household applications and medical textiles, along with an increasing demand for technical textiles with high-performance properties and end-user applications.

Regarding the international textile market overview, the United States are a leading producer and exporter of raw cotton, and the top importer of raw textiles and garments. Europe holds more than 20% of the global textile industry, with Germany, Spain, France, Italy, Portugal at the forefront. European high-quality textiles and premium fashion products are in growing demand, both in high-income countries and emerging countries. Sweden and Finland, and central European countries such as Germany, the Czech Republic or Slovenia, registered the highest share for technical textiles in national textile turnover in 2020. India is the third-largest textile manufacturing industry with 6% of the total textile production globally, while China is the world's leading producer and exporter of both raw textiles and garments.

The COVID-19 outbreak led to **global trade restrictions** due to disrupted supply chains and a decline in textile product consumption amid imposed lockdowns that negatively impacted the market as well. However, a strong market recovery is to be expected during the forecast period with government support and increasing public awareness in terms of effective precautionary measures.

RESULTS AND CONCLUSIONS

Technical Textiles continue their steady rise in the share of total EU textile production, with turnover (including yarn-type, fabric-type and non-woven materials but excluding any made-up articles) reaching about 24 billion € or 27% of total textile industry for 2016 (EURATEX). Exact figures for this part of the industry are difficult to compute, due to the dual use of many yarns and fabrics for both technical and conventional applications.

The EC provided a consistent strategic plan with NMBP programmes, offering regularity, stability, continuity in composites research. During the 2008-2017 period, within the 7th Work programme (FP7), more than 75 projects were funded regarding spinning fibres, processing yarns (including bio-based), carbon fibre production, smart textiles and functional garments, personal protective clothing, FRPs in aeronautic, automotive, construction and railway sectors applications, specific functional textiles, and medical textiles. In the next funding scheme, Horizon Europe (H2020, 2014-2026), more than 120 projects will be implemented: from the production of fibres and yarns, to the application in garments, smart textiles, wearables, FRPs in transport, aerospace, construction, structural health monitoring, nano-composite solutions, storage devices, medical textiles and exoskeletons.

Fig.1 shows the difference between the FP7 and H2020 programmes in terms of funded projects related to textiles.

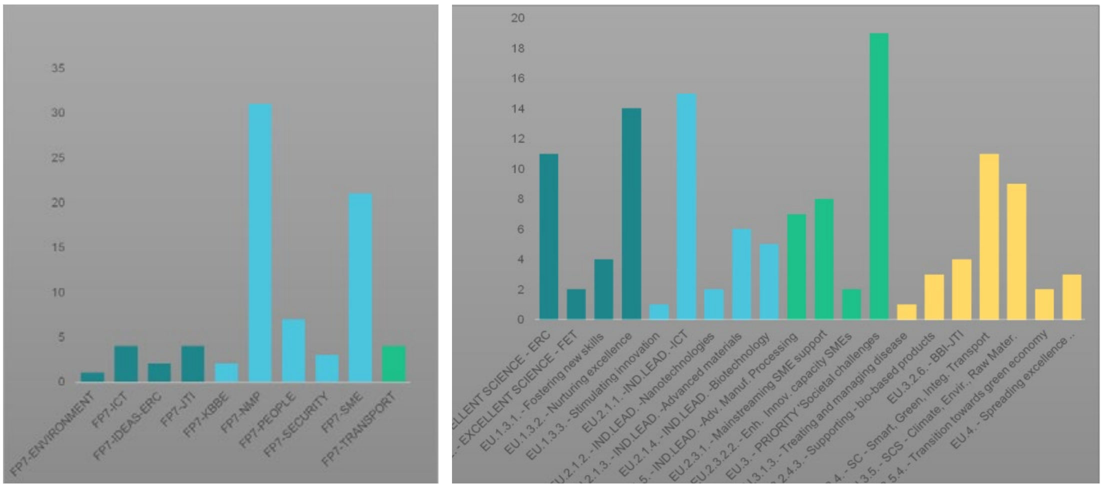


Figure 1. FP7 and H2020 funded projects related to textiles

Dual use products, services and technologies can address the needs of both the defence and civil communities. This can further contribute to the EU industry development. SMEs participating in defence markets today are (almost) exclusively involved in dual-use activities. Armed Forces rely increasingly on the development of civil industrial products and technologies, as well as on the growing research & technologies for multiple applications, such as nano-electronics, unmanned systems, synthetic biology, big data, 3D printing. In 2013 licensed exports of dual use products amounted to 48 billion € and represented 3.1% of total extra-EU exports.

There are manifold opportunities for the application of structural and multifunctional composites and novel materials with extreme physical properties, such as super strong, extremely light-weight, resistant to low and high temperature, unique electromagnetic properties, high performance electromagnetic wave absorbing materials; smart textiles, wearables, health monitoring and injury prevention devices, and inspection/ monitoring methods, both for civil and military applications.

However, there are still several challenges to address when delivering new materials to the market and adopting them for dual use, such as reliability and robustness to meet military standards, capacity to endure extreme environments, better health monitoring and care provision, decision making at individual level, and affordable production and manufacturing.

REFERENCES

https://cordis.europa.eu/projects
https://www.mordorintelligence.com/industry-reports/europe-textile-industry
https://euratex.eu/news/european-textile-and-clothing-sector-consolidates-satisfactory-evolution-in-2018/
https://www.grandviewresearch.com/industry-analysis/textile-market
https://www.mordorintelligence.com/industry-reports/global-textile-industry---growth-trends-and-forecast-2019---2024

STILE: Smart TextILEs in defence

José Manuel Ramos Fernández[1], José María García Gonzalo[1](*), Josué Ferri Pascual[1], Gilda Santos[2], Cláudio Santos[3], Paulo Reinier Gonçalves[3], Giuseppe G. Daquino[4]

[1] AITEX; [2] CITEVE; [3] INEGI; [4] European Defence Agency

(*) Email: jgarcia@aitex.es

STILE PROJECT

Smart Textiles are a new generation of materials and systems with very interesting multifunctional properties (e.g. camouflage, moisture management, electronics integrated in textiles). These properties, together with the possibility of integrating the materials and systems in uniforms and platforms, have drawn the attention of the defence stakeholders. In this context, the European Defence Agency (EDA) has incorporated Smart Textiles into the Strategy Research Agenda (SRA) of the CapTech Materials & Structures, and a Technology Building Block (TBB) is devoted to this area. Furthermore, other EDA CapTechs such as the CapTech CBRN and Human Factors and the CapTech Ground Systems, have performed initiatives related to "Smart Textiles".
Throughout 2018, EDA launched an OB study dedicated to "Smart textiles in defence: looking at the soldiers of the future". This project, named STILE, was assigned to a consortium led by the Spanish Textile Research Institute (AITEX), in collaboration with the Centro Tecnológico das Indústrias Têxtil e do Vestuário de Portugal (CITEVE) and Instituto de Ciência e Inovaçao em Engenharia Mecânica e Engenharia Industrial (INEGI).
The STILE project was designed with the aim of laying the foundation for a European Multifunctional Smart Textile industry focusing on defence and, specifically, tackling aspects of functionality, integration, comfort and lightweight.

FIRST STAGE

The first stage of the project was focused on two main objectives. The first one was the development of a credible roadmap, with the final goal of establishing how to pass from the current state of the art to a full system that integrates several functionalities in a textile substrate. The second objective was devoted to the fabrication of a proof of concept, integrating various functionalities in the same smart multifunctional textile combat system. In particular, the STILE model integrates the following functionalities:

Signature management. A textile with specific properties was developed by means of thermochromic formulations, studies of colour fastness to light, and measurements of colour coordinates in order to provide a multispectral camouflage with a special focus on visual, near infrared and thermal spectra, and aiming at decreasing the visibility of the soldier in combat zones, in both static and moving positions.
Monitoring of environmental parameters and CBR threats. Several specific sensors were integrated in the combat uniform in order to detect the presence of hazardous agents in the environment surrounding the soldier.
Improved mobility. The smart multifunctional textile system was designed and produced taking into account parameters such as ergonomics, homogeneous distribution of weight, wearers' comfort, modularity, freedom of movement, and functional properties based on a body mapping study aiming at defining specific functionalities for each body area (such as flexibility, compression, and ventilation areas). Regarding the wearable electronic components, the most flexible, light and miniaturized elements were selected.
Flame retardancy, water and dirt repellence, and anti-mosquito solution. Textile fibres and materials with flame retardant properties were selected, and the rest of the components were positioned in specific compartments, to avoid exposure to heat and flame. Other functionalities, such as water and dirt repellence and an anti-mosquito solution, were incorporated using the most innovative functional finishing technologies combined with thermochromic formulations and underwent through colour fastness tests to washing cycles and colour fastness tests to light, among others.
Physiological monitoring. The monitoring of physiological parameters of the soldiers was carried out by means of heart rate sensors located in the inner layer of the smart multifunctional textile system, in contact with the body skin, and integrated in the textile substrate using conductive textiles and printed electronic techniques. The special stretching and flexible properties of the electrodes offered a comfortable solution without the need of hard and rigid elements.

Temperature regulation. A system capable of regulating the thermal comfort of the soldier, adapting it to the weather conditions while considering the physical activity carried out, was incorporated to the combat uniform. This solution included both heating and cooling effects through active and passive mechanisms.

Communication and wireless exchanging data. All the sensors integrated in the smart multifunctional textile system are capable of sending the registered data via wireless networks. This enables the monitoring of different parameters related to the state of the soldier in the combat field. The various parameters can be adjusted, activated or deactivated from the control centre located on a smartphone. The information is shown by means of a mobile app that was ad hoc developed to show the valuable information in a user-friendly and intuitive way.

SIMULATION

Two simulation models were developed to evaluate the main concepts regarding the thermal protection capacity of the garment and the thermal signature under different ambient conditions.

A FEM (Finite Element Method) model was developed to study the thermal protection capacity of the clothing assembly. Three exposure scenarios were defined and simulated in order to evaluate the fire protection capacity by analysing the skin burning degree. In the same way, three ambient exposure scenarios were defined and simulated with the objective of analysing the thermal signature of the garment under different body metabolic rates.

Fig. 1 Details of the STILE Proof of concept

SECOND PHASE

Aiming at making the most of the results achieved during the first phase of the project, the design of the proof of concept was improved throughout the second phase, considering aspects such as the encryption of data during signal transmissions. Additionally, the integration of the electronic components and cabling in the textile system was reviewed in parallel to the increased modularity regarding the location option for the battery and control box pockets.

The depth of the formerly developed simulation was refined. Moreover, the numerical results obtained were compared with the experimental results, taking the skin and different garment zones into account.

A full testing campaign of the proof of concept was carried out, considering different parameters in both controlled (laboratory conditions) and non-controlled (real conditions) environments.

Within the scope of the STILE project, the International Forum on Advanced and digitalised Smart Textiles (IFAST) was organized. The event took place online on 15 and 16 June 2021, with the objective of evaluating the development of advanced smart textiles in the European defence sector, aiming at laying the foundation of a possible European future dual use programme for multifunctional smart textiles, as well as disseminating the results of the STILE project among a wider audience.

EXHIBITION

AITEX capabilities related to smart textiles and digitalisation

Campos Juan(*), García José Maria, Ferri Josué

Asociación de Investigación de la Industria Textil – AITEX. Plaza Emilio Sala 1, 03801 Alcoy, SPAIN.

(*)Email: jcampos@aitex.es

ABOUT AITEX

The Textile Industry Research Association –AITEX– is a private research association that performs characterisation trials and certification of textile materials and articles for a wide range of sectors including interior design, fashion, work wear, healthcare, sports and leisure, land and sea transport, defence, security, aerospace and sports surfaces.

AITEX's core objective is to create and transfer knowledge of textiles to the private sector, making the textile industry more competitive and opening up doors to new opportunities with a high added-value factor. The Institute promotes modernisation and the introduction of emerging technologies through its on-going R+D activities and other projects, which contribute to the evolution of the textile industry. Also, it issues the most appropriate product certifications to allow an article to compete in the international marketplace and facilitate its introduction into high-end niche markets.

AITEX is Spain's leading research and innovation centre and provider of advanced technical services for the textile industry. The Institute has a network of nine international offices providing support to its associates and clients in fifty countries. This has led to the Institute becoming one of Europe's leading research centres. AITEX's research work has culminated in the signing of several bilateral agreements with centres from around the world to exchange experiences, participate in international R+D projects and generate know-how to provide the private sector with a value-added factor for their products. The Institute's laboratory services offer its members the most up-to-date equipment and infrastructure for the characterisation of products, QA and certification to the most demanding international standards and regulations. AITEX is one of Europe's best equipped centres, with the widest scope of technical accreditation facilities, with ENAC – ILAC approval (the national and European accreditation bodies).

AITEX is also heavily involved in specialist technical training and offers a wide selection of in-company courses as well as two University degrees in collaboration with the Polytechnic University of Valencia (UPV): the Master's Degree in Textile Engineering and the University Diploma on textile applications.

AITEX'S EXPERTISE ON SMART TEXTILES

AITEX works on the following domains of Smart Textiles:

I. Textronic sensorisation which consist of the integration of electronic devices in textile structures. This line of research studies the development of projects concerned with the following:

- Monitoring physiological variables to control the wearer's state of health.
- A textile climatisation system to keep the wearer comfortable in hot or cold weather.
- Sensorised fabrics to protect the wearer in hostile manufacturing environments.
- Light-emitting fabrics with integrated LEDs.
- Kinetic textile systems which can generate power using movement or impacts.

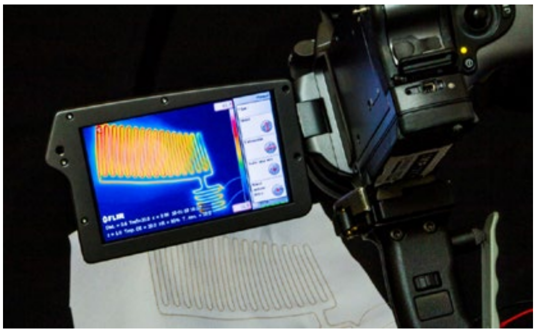


Fig. 1. Heating textile

II. Printed electronics.

Advances in printers and inks make it possible that successive layers of material can be built up, each with different conductive and electrochemical properties and characteristics which, in turn, mean that new applications can be created such as:

- Light-emitting textile structures.
- Photovoltaic textile structures.
- Self-heating textile structures.
- Pressure, tactile, chemical, and biological sensors.
- Flexible printed circuits.

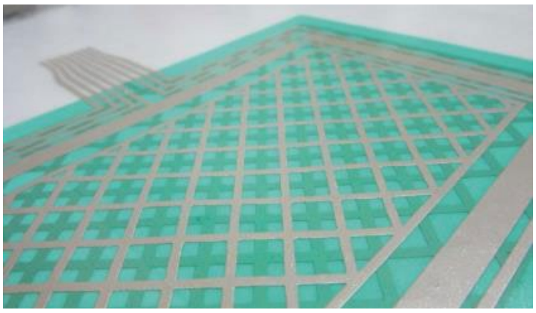


Fig. 2. Printed electronics on a textile substrate

III. The functionalisation of yarns and fabrics

Advances in materials have meant that fibre, yarn, fabric or the finished garment itself can now be enhanced with functions:

- Photo and thermoactive yarns.
- Luminescent yarns.
- Photovoltaic fabrics.
- Technical textiles.

IV. 3D printing

3D printing allows for much shorter lead times between product design and final production and it is cheaper and easier to operate than other additive manufacturing processes. This research line mainly studies the following:

- Flexible plastic casings for wearable electronic devices.
- Low-cost engineering components for their incorporation into production processes.
- Prototypes developed with conductive materials.

AITEX'S BACKGROUND IN DIGITALISATION

AITEX also has a broad know-how in Digitalisation. Among the many advantages of the industrial applications provided by digitalisation and Industry 4.0, digitalisation helps optimising industrial processes, improving performance, sales management and contact between clients and suppliers, as well as providing better data management tools to aid the decision-making process.

In this sense, AITEX woks in the following digitalisation areas:

I. Artificial Vision.

AV is an extremely useful tool for acquiring, processing and analysing images captured during high-speed repetitive processes which would be impossible for the naked eye.

Fig. 3. Example of AV cameras

The Institute is working on the following research and development lines:

- New image-capturing and processing techniques to develop automatic default-detection systems for the textile manufacturing line.
- Analysis of the critical points in the weaving process using high-speed cameras.
- Analytical studies on the impact of a bullet on bulletproof panels using high-speed cameras.

II. RFID technology.

Radio Frequency Identification (RFID) improves the traceability of products through the supply chain and optimises stock control, speeds up order processing and reduces picking errors. AITEX is working on projects related to the following lines:

- The development of smart ID and tracking systems for in-store clothing stock.
- The development of emitting antennae integrated into a garment.
- Integrating antennae into a PPE to track the wearer.

III. Industry 4.0.

The core goal of Industry 4.0 is the introduction of digital technology into industry to allow devices and systems to interact and modify or adapt processes, products and business models. To this end, help will be provided to textile companies seeking to implant innovative digital systems in the following fields:

- Business solutions.
- Smart solutions and control (Big Data & Analytics).
- Collaborative platforms.
- Cyber security.
- Computing and the cloud.
- Connectivity and mobility.
- 3D printing.
- Advanced robotics.
- Embedded sensors and systems.

IV. Information systems and e business.

The above systems help to improve productivity and process control, as well as to optimise resource management. The Institute offers a consultancy service for textile and garment-making companies who wish to incorporate advanced freeware management tools such as Eneboo ERP Textil, Alfresco document management and Saiku Business Intelligence into their business.

Ultra-light modular bullet proof integral solution for dismounted soldier protection - VESTLIFE

José G.[1](*), Rosa L.[1], Gilda S.[2], Cristina G.[3], Sanna W.[4], Massimiliano V.[5], Paul B.[6]
[1]AITEX; [2]CITEVE; [3]TECNALIA; [4]FY COMPOSITES; [5]PETROCERAMICS; [6]BRAPA
(*)Email: jgisbert@aitex.es

ABSTRACT

The main objective of the VESTLIFE project is to develop a new comfortable, lightweight modular and integral solution for ballistic protection of the dismounted soldier, that also integrates a CBRN protection system.

INTRODUCTION

Human factors are critical for the health and efficiency of our military forces, and current solutions can be improved to benefit dismounted soldiers in terms of comfort, protection, and weight through novel technological approaches. The VESTLIFE solution will be:

INTEGRAL: Because it will cover main parts of the body where critical injuries may be caused.
MODULAR: Because it will be adaptative to the forecasted risk of the mission in terms of protected areas, and the level of protection of each covered area, including protection for:

- LEVEL IIIA: through soft panels developed with 3-layer fabric knitting technology.
- LEVEL III: by auxetic composites.
- LEVEL IV: by means of lighter 3D printed ceramics.

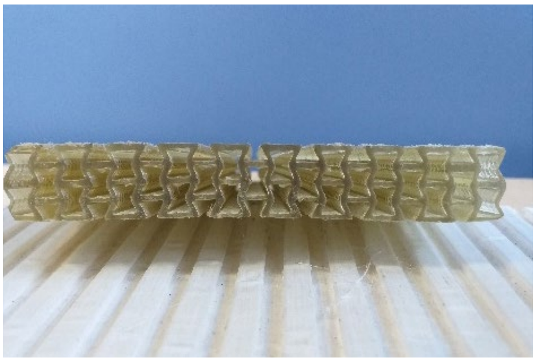
COMFORTABLE: Ergonomics and modular design will include non-protective zones (body areas with very low injury risk), where heat transfer between human and environment will be promoted. Utilization of transpirable materials and structures.
LIGHTWEIGHT: 25-35% weight reduction of the current commercial panel solutions and 15-20% decrease of the trauma depth (back face signature).
CBRN threat detection: Integration of CBRN detection sensors.

RESULTS AND CONCLUSIONS

Compared to current ballistic protections, the VESTLIFE prototypes can improve the following characteristics in a wide variety of different bullet vests:

SOFT PANELS	HARD PLATES
• Air permeability: from current 0.14mm/s to 932.8mm/s of air flow able to pass through the new knitted fabrics. • Up to 30% blunt trauma decrease. • Up to 23,9% soft panel weight decrease.	• Back face signature reduction up to 30%. • Weight reduction up to 24%.

Table 1. Vestlife partial results



Auxetic material for ballistic panel backing

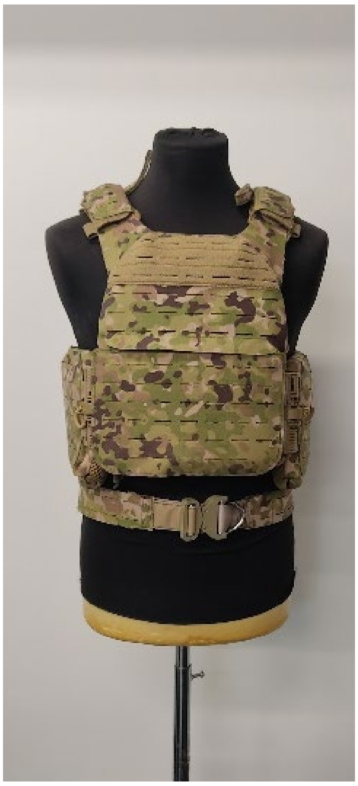
Ballistic 3D printed ceramics tile. VESTLIFE LOGO

3D prototype. Ergonomics front part ballistic backing

Ballistic female prototype for level IV requirement

Fig. 1. VESTLIFE technical solutions

Standard vest showing modularity (add-ons)



Slim vest

Fig. 2. VESTLIFE vest prototypes

VESTLIFE has links to the core business of Captech Materials, Captech CBRN & Human Factors and Captech Land.

ACKNOWLEDGMENTS

This project has received funding, under Grant Agreement No 800876, from the European Union's Preparatory Action on Defence Research call on the topic of 'Force protection and advanced soldier systems beyond current programmes', and subtopic 'Tailor-made blast, ballistic and CBRN protection of military personnel'.

The VESTLIFE consortium expresses their gratitude to the Experts of the Advisory Board (Major Alfonso Cubero Franco, Major Ricardo Silva, Major Jari Tiilikka, Ltc. Mª del Rosario Quesada Medina, Lieutenant Jorge Sanchez Carcelen, and Ing. M.H. Martijn Stoop, for their active participation and always valuable contributions helping us in the solution development process based on the real needs of the soldiers.

The consortium would also like to specially thank Shahzad Ali for his guidance and support in the technical and managerial progress of the project.

New composites embroidered with TFP technology

Domenech-Pastor, Jorge[1] (*), Silvestre Rocio[1]; Diaz-García Pablo[2], Garcia Daniel[3]

[1] Asociación de Investigación de la Industria Textil – AITEX. Plaza Emilio Sala 1, 03801 Alcoy, SPAIN.

[2] Universitat Politècnica de València (UPV), Escuela Politécnica Superior de Alcoy, Ingeniería Textil y Papelera (DITEXPA)

[3] Universitat Politècnica de València (UPV), Escuela Politécnica Superior de Alcoy, Instituto de Tecnología de Materiales (ITM)

(*)Email: jdomenech@aitex.es

ABSTRACT

TFP technology (Tailored Fibre Placement) brings a great opportunity to develop composites with better properties than the ones obtained by traditional methods. TFP allows to align the fibres in the right directions according to the effort-reducing fibre consumptions and costs. This work explores the advantages of using this technology to develop composites with less fibre and with better properties.

In this study different types of fibre alignments were analysed under flexural efforts. Composites were made using Resin Transfer Moulding (RTM) once the fibre was embroidered to a non-woven textile. During the RTM process a polyester resin was used. The use of TFP allows for infinite possibilities in designs and shapes adapting the fibre to the geometry of the piece. The use of this TFP technology allows reducing the number or layers when building the composite and it avoids unnecessary superposition of carbon fibre layers to achieve better properties in a specific direction.

Two designs have been analysed under flexural stress of composites with embroidered carbon fibre using TFP technology.

INTRODUCTION

A composite (or composite material) consists of the combination of several materials that, when combined, offer better mechanical properties than individual materials [3]. Composites have been used for centuries when mud and straw were combined to form adobe bricks that were used in the construction of houses [1]. It was not until the twentieth century, when the first polymeric composite materials appeared, that they began to be used in automotive and aeronautical applications [2]. Over the years, the use of these composite materials has become widespread as they allow, with equal volume and lower density, to obtain lighter pieces with similar characteristics. In some cases they show better mechanical properties than other materials such as steel.

Currently, the manufacturing process of composites is a problem since the processing time, the cost of the materials and the generated waste is very high. Accordingly, one of the main objectives of the industry is to reduce these problems by combining the TFP embroidery technology with less labour-intensive composite manufacturing technologies.

In the composite industry, glass and carbon fibres are generally the most widely used materials because of their high strength to weight ratio. Nevertheless, carbon fibres are the predominant high strength and modulus reinforcement used in the fabrication of high-performance polymer-matrix composites. Carbon fibres typically contain more than 90 weight percentage of carbon and have remarkable properties. In general, they include high tensile strength (up to 7 GPa), good compressive strength (up to 3 GPa), high tensile modulus (200 up to 900 GPa), low density (1.75 up to 2.18 g/cm^3), good temperature resistance, low thermal expansion, good electrical and thermal conductivity and chemical resistance.

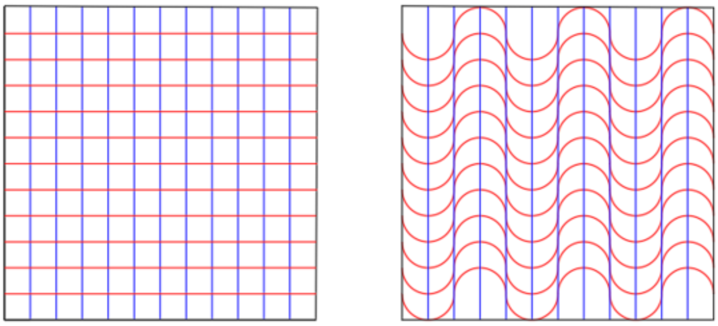
OBJECTIVES

This study aims – without using plain fabrics – to evaluate the behaviour under flexural strength efforts of tailored fibre placement reinforced polymers produced by embroidery technology in two different structures. One with fibres oriented in a horizontal and vertical direction (simulating woven fabrics) named as "SAMPLE1", and another with fibres with curvilinear orientations named "SAMPLE2".

MATERIALS

The carbon fibre used to develop the composite samples was a multifilament of 880 TEX from manufacturer Tairyfil. This carbon fibre was embroidered on a polypropylene non-woven substrate of 0.25mm thickness and 30g/m^2.

The placement of the carbon yarns on the non-woven substrate is done covering the entire surface of the substrate, either vertically and horizontally in the first example (SAMPLE1), or vertically and curvilinear-waved-horizontally in the second (SAMPLE2).



Sample 1 Sample 2

Fig. 1 Designs of fibre placement.

The weight per square meter of the obtained products does not present significant differences. The resulting SAMPLE1 embroidered substrate has a weight per square meter of 646,79g/m^2, and Sample2 of 524,15g/m^2.

As matrix for the composite has been used: RESICHIM 209, a polyester DCPD (DiCycloPentadiene Resin) produced by Gazechim.

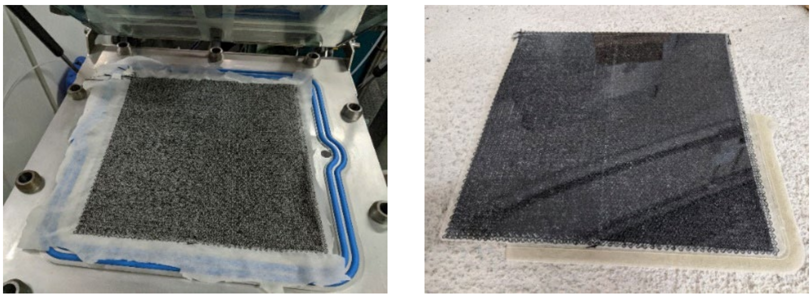


Fig. 2 Embroidered samples using TFP technology and composite obtained.

RESULTS AND CONCLUSIONS

From the results obtained after flexural testing with the Universal Testing Machine (Table 1), it is observed that curvilinear designs (SAMPLE2) improve flexural properties as there is an increase in flexural strength from 88,85 MPa for the SAMPLE1 sample, to 105,54 MPa for the SAMPLE2 sample, which represents an increase of 19%. Regarding the Young Module, a notable increase can be observed with respect to the reference sample SAMPLE1, going from 2.207,53 MPa to 3.153,99 MPa, which represents an increase of 43%.

Sample	Flexural max. strength (MPa)	Young Module (MPa)
SAMPLE1	88,85 ± 4,1	2.207,53 ± 270
SAMPLE2	105,54 ± 3,5	3.153,99 ± 299

Table 1 Results from flexural strength tests.

In the case under study, a clear improvement is obtained by using curvilinear fibre arrangements, as mechanical properties are improved by using less amount of carbon fibre. TFP seems to be a technology with a lot of potential to develop smarter composites.

ACKNOWLEDGMENTS

This study has been done by AITEX in the framework of LIGHTCOMP 2020 project. This project has the support of the Conselleria d'Economia Sostenible, Sectors Productius, Comerç i Treball of the Generalitat Valenciana through IVACE, and is co-financed by the FEDER funds of the EU, within the Operational Program FEDER of the Valencian Community 2014 -2020.

REFERENCES

1. Mohammed Ahmed, F., & Lucas, S. (2016). *Jute fibre reinforcement of Adobe Brick as a means to providing cheap and sustainable housing.*
2. Balakrishnan, P., John, M. J., Pothen, L., Sreekala, M. S., & Thomas, S. (2016). *Natural fibre and polymer matrix composites and their applications in aerospace engineering. In Advanced composite materials for aerospace engineering* (pp. 365-383). Woodhead Publishing.
3. Santiago, M. O., Marín, C. G., & Fernández, J. R. (2003). *Los Composites. Características y aplicaciones en la edificación.* Informes de la Construcción, 54(484), 45-62.

Carbon based nanomaterials for advanced properties in polymers: applications in the defence sector

A. López-Pérez, M.D. Romero-Sánchez(*), I. Rodríguez-Pastor, I. Martín-Gullón
Applynano Solutions, S.L., Scientific Parc of Alicante. 03690 Alicante-Spain
(*)Email: md.romero@applynano.com

ABSTRACT

This work collects different advanced properties obtained by the incorporation of carbon-based nanomaterials to polymeric formulations, both in coatings and bulk applications. These properties include thermal and electrical conductivity, sensor capacity (adsorption of molecules and compounds), UV radiation resistance.

INTRODUCTION

Applynano Solutions is focusing its efforts on the development of carbon-based nanomaterials to be used in polymer formulations conferring new properties and functionalities to the materials (bulk and surface coating applications), enhancing their performance and increasing the potential applications of polymers. Carbon-based materials are transversal materials, and therefore suitable for their use in different sectors, such as construction, automotive, aerospace, defence, sports, electronics, etc.

There are different types of carbon-based nanomaterials, each of them providing different properties. It is well known in literature that the use of carbon-based nanomaterials, such as nanofibres or carbon nanotubes, greatly increases mechanical properties of both thermoplastic and thermosetting polymers. Moreover, the incorporation of carbon-based nanomaterials to polymer formulations also provides advanced and innovative properties such as thermal and electrical conductivities, barrier properties or sensor capacity.

In this paper, results obtained by Applynano for different carbon-based nanomaterials incorporated to polymer formulations suitable for applications in the defence sector are shown and discussed.

RESULTS AND CONCLUSIONS

Garments in the defence sector are designed to protect against environmental hazards, heat, flames and radiation. However, these clothes reduce or even completely prevent the body heat exchange with the environment, increasing body temperature, humidity levels and subsequently producing thermal stress related problems. The heart rate can also rise, impacting garment users and making them more susceptible to medical complications and heart attacks [1,2].

Applynano has developed a technology based on composites formed by Phase Change Materials (PCMs, latent heat storage capacity) and carbon materials (CMs, high thermal conductivity). These composites, incorporated to coatings may be used in providing textiles and fabrics with a heat storage capacity and heat dissipation capacity to improve the garment user's comfort and reduce thermal stress. Figure 1 shows results obtained for composites with a different PCM:CM ratio: thermal energy storage capacity by Differential Scanning Calorimetry and thermal conductivity.

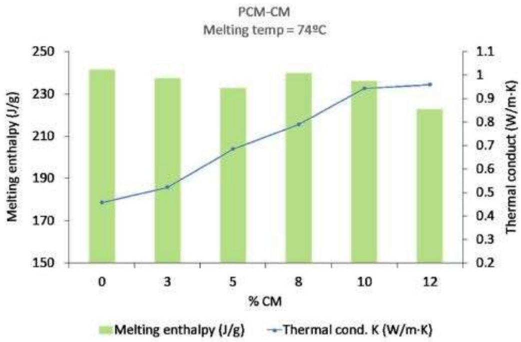


Fig. 1. Thermal energy storage (J/g) and thermal conductivity of the different composites prepared with PCM-CM.

On the other hand, the electrical conductivity of carbon nanotubes may also be exploited to provide polymers with advanced properties in the defence sector in different aspects: electrically conductive or dissipative coatings to avoid electrical charges (coatings for textiles, infrastructures, etc.) [3] (Figure 2). The RF electromagnetic field and low-frequency electrical fields produced by electronic devices, such as phones, computers, radio stations, may be blocked by electrically conductive coatings [4].

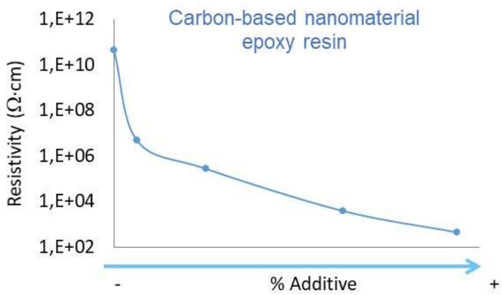


Fig. 2. Electrical resistivity (Ω·cm) of epoxy resin with carbon-based nanomaterial: dissipative and electrically conductive ranges.

Additionally, coatings or bulk materials with self-responsiveness properties may be obtained by using carbon-based nanomaterials. The self-heating capacity of carbon nanotubes-based polymers (Joule effect) allows for the heating of materials (coatings in textiles, bulk materials) under voltage application: self-curing and de-icing capacity [5, 6], which turns to be important for in-situ reparations and aircrafts de-icing properties, respectively. Currently, graphene, as a new material presented on the media as a technological revolution, is under research for its different applications, including high performance as well as industrial applications: aeronautics and aircrafts, microchips for electronic devices, conductive inks for printed circuits, faster computers with low energy consumption and storage capacity, high quality wireless communication systems or sensor applications due to its capacity for adsorption of chemical compounds. Graphene oxide developed and produced by Applynano has been demonstrated as an antibacterial compound for polymer formulations. Figure 3 shows the antibacterial activity of a graphene-based polyester resin towards Staphylococcus aureus and E.coli (ISO 22196:2011).

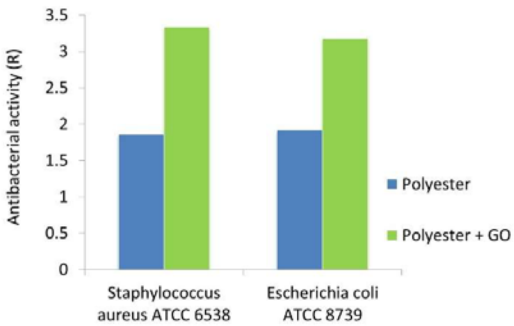


Fig. 3. Antibacterial activity of graphene-based polyester resin under ISO 22196:2011.

Graphene oxide produced by Applynano has been also proven to be an additive, providing UV resistance and corrosion resistance to polymeric compounds.

Chemically, graphene oxide is a material composed of carbon and oxygen atoms. This chemical composition of graphene oxide rich on polar and oxygenated groups (hydroxyl, carbonyl, carboxyl, epoxy, lactones, etc.) favours a high compatibility within the polymeric materials used for coatings (water and solvent based dispersions, thermosetting, thermoplastics, etc.). Keeping this in mind, last research in Applynano is related to the chemical surface functionalisation of graphene oxide by the introduction of specific chemical groups (e.g. amine, carboxylic and/or silane groups, different chain lengths) [7] for higher compatibility and selectivity in the previously mentioned applications: UV resistance in different wavelength ranges, selectivity to different compounds (e.g. organic, virus, bacteria, etc.). Figure 4 shows the absorbance of graphene oxide in the UV-visible range.

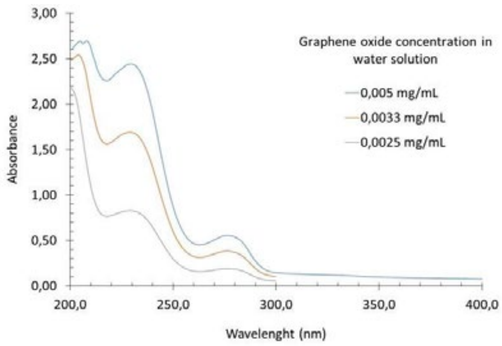


Fig. 4. UV-vis absorbance of graphene oxide in water-based solution.

ACKNOWLEDGMENTS

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REFERENCES

1. I. Holmér, K. Kuklane, C. Gao. *Thermal stress on firefighters in extreme heat exposure. In Protective clothing-towards balanced protection.* Proc.3rd Eur.Conf. Protective Clothing (ECPC) Gdynia, 10-12 May 2006. Poland.
2. T.M. McLellan, G.A. Selkirk. *The Management of Heat Stress for the Firefighter: A Review of Work Conducted on Behalf of the Toronto Fire Service.* Industrial Health 44 (2006) 414-426.
3. B. Del Moral, I. Martín Gullón, R. Navarro, O. Galao, F.J. Baeza, E. Zornoza, B. Calderón, I. Rodríguez, N. Arnaiz, M.D. Romero Sánchez, P. Garcés. *The effect of Different Oxygen Surface Functionalization of Carbon Nanotubes on the Electrical Resistivity and Strain Sensing Function of Cement Pastes.* Nanomaterials (2020) 10, 807. doi:10.3390/nano10040807.
4. Marta González, Guillermo Mokry, María de Nicolás, Juan Baselga and Javier Pozuelo (July 20th 2016). *Carbon Nanotube Composites as Electromagnetic Shielding Materials in GHz Range, Carbon Nanotubes. I*n: - Current Progress of their Polymer Composites, Mohamed Reda Berber and Inas Hazzaa Hafez, IntechOpen, DOI: 10.5772/62508.
5. L. Guadagno, F. Foglia, R. Pantani, M.D. Romero Sánchez, B. Calderón, L. Vertuccio. *Low-Voltage Icing Protection Film for Automotive and Aeronautical Industries.* Nanomaterials (2020) 10, 1343, doi:10.3390/nano10071343
6. L. Vertuccio, F. Foglia, R. Pantani, M.D. Romero Sánchez, B. Calderón, L. Guadagno. *Carbon nanotubes and expanded graphite based bulk nanocomposites for de-icing applications.* Composites Part B 207 (2021) 108583. https://doi.org/10.1016/j.compositesb.2020.108583
7. Patent. *Procedimiento de obtención de óxido de grafeno carboxilado monocapa y óxido de grafeno carboxilado monocapa obtenido (Procedure for obtaining monolayered carboxylated graphene oxide and obtained monolayered carboxylated graphene oxide).* Applynano Solutions, S.L. ES2787504.

Presentation of Bren-Tronics

Nathalie Perrier Chomel
Bren-Tronics
Email: n.perrier@bren-tronics.fr

INTRODUCTION

Bren-Tronics has cumulated over 48 years of experience in the design, production and management of smart rechargeable batteries for diversified military applications. Always at the state of the art, Bren-Tronics, Inc. is known and recognized worldwide for designing the first Li-ion rechargeable military batteries in 1995. The company continues to innovate to provide the perfect match between power, energy, weight and safety for the growing diversified demands and applications.
Users are using less and less primary batteries nowadays, and their confidence in the rechargeable technology has grown every year, first due to the fact that they have been able to experience their durability on the field, and also because of the gain in weight and available capacity.
Even though current rechargeable Li-ion batteries give satisfactory autonomy, it has been very clearly stated that the Future soldiers within 10 years will not be able to recharge their batteries at their support zone if they are in combat missions.
Consequently, the 2025 Future soldier will absolutely need the highest available capacity batteries with centralized power and a recharging capability on the field (with or without the help of a vehicle).
With over 12 years' worth of experience in major Future Soldier Programs, Bren-Tronics offers a centralized battery for the dismounted soldier. These lead edge technology battery systems drastically reduce weight and optimize running time. Today, our unique 10.8V SMP® and 14.4V NETT+® rechargeable battery family offers the highest energy density possible (+212Wh/kg) for a true wearable soldier power system.

The battery Nett+ developed by Bren-Tronics was selected and used in the STILE Project to feed the electronic system of the proof of concept due to its ruggedized features, providing a high performance in the tests carried out. Bren-Tronics already supplies such soldier portable batteries in European Projects for the Future Soldier in Germany (IDZ program), the Netherlands (VOSS) and Spain (SISCAP).
Bren-Tronics anticipated the need for field recharging a number of years ago and is now able to provide different chargers that can be dedicated for one type of battery, or that can recharge different types of batteries at the same time utilising solar energy (Flex-Charger).
Each charger includes advanced features such as Solar Maximum Power Point Tracking, and DC Vehicle capability coupled with simultaneous battery charging.

Moreover, Bren-Tronics's newest Advanced Battery Charger (ABC) can also be powered from solar energy, and weighs only 9 kg. For missions with a higher durability of 48 hours, a universal charger like this is ideally suited for field use or for fast charging in workshops.

Military power solutions must operate to its limits (or beyond). All Bren-Tronics products are designed, tested and manufactured to meet the most severe climate environment applications.

Bren-Tronics was awarded the next generation of Conformable Wearable Battery (CWB) manufacturing contract

Thanks to its know-how and unique technology, Bren-Tronics is the only small business among the four awardees for the $1.25 Billion Indefinite Delivery / Indefinite Quantity (IDIQ) contract to manufacture the CWB by the U.S. Army Contracting Command, Aberdeen Proving Ground - an exciting and challenging program.

The Conformable Wearable Battery (CWB) is a rechargeable power source for the Army's Nett Warrior Soldier System (USA). This battery provides a significant improvement since the design is flexible and it allows the battery to be carried in various places, thus making it highly ergonomic in nature. Additionally, using rechargeable technology reduces war-fighter operating and support costs, and decreases both the logistic footprint and quantity of batteries processed as hazardous waste.

Since 2018, Bren-Tronics has been working on designing a CWB battery to match US Army needs and is now ready to provide a 1,000,000 of units over 9 years starting in 2022. Moreover, Bren-Tronics newest generation of universal chargers Advanced Battery Charger (ABC) is able to charge several tens of CWB batteries in less than three hours.

Bren-Tronics is proud to participate in providing such solutions to help enhanced mobility for the war-fighter.

CITEVE - Technological Centre for the Textile and Clothing Industry of Portugal

Gilda Santos
CITEVE – Technological Centre for the Textile and Clothing Industries of Portugal, V.N. Famalicão, Portugal.
Email: gsantos@citeve.pt

CITEVE is a private non-profit organization active since 1989, being a reference organization within the national and European scene regarding research, innovation, and technology transfer promotion for the Textile & Clothing Industry. With a deep knowledge of the most advanced & innovative technical textile technologies, CITEVE's mission is to support the technical and technological development of the textile & clothing industry, promoting innovation, inducing new capacities and new competences, as well as helping on the definition of industrial public policies.

CITEVE OVERVIEW

CITEVE offers technological services at the highest level in different areas: laboratorial activities, technological consultancy & development, R&D and innovation, technology surveillance, product certification, training and fashion intelligence.
CITEVE's laboratories are equipped with the best available technologies controlled by a highly qualified staff and are internationally accredited for more than 446 tests according to 900 different standards. Accredited by several national and international brands, CITEVE is responsible for performing around 180.000 tests per year. CITEVE's labs are specialized in material and product testing, such as chemical and physical testing, measurement of comfort and new functionalities, fire behaviour, toxicological substances, microbiological tests, geotextiles, automotive, protective clothing...
In the field of R&D and new product development, CITEVE gathers expertise within the most advanced and innovative technologies such as hotmelt, coating, laminating, digital printing, 3D knitting, laser welding or seamless knitting. These prototyping technological facilities are managed by specialized technical and scientific staff, with competences in textile and clothing processes and dedicated to demonstration/reengineering and product/process development.
Consulting and technological development also includes the sustainable production area, integrating services and expertise in LCA, environmental technologies, energy management, health and safety, waste management and quality management.
R&D and innovation oriented to market demand is one of the major strategic lines of CITEVE and is structured into the following activities:

- National and European R&D projects focused on product/process development, either by private contract or through programs co-financed by public authorities.
- Promotion, demonstration and transfer of emerging technologies and knowledge.
- Technology surveillance, benchmarking and IPR management are also competences to support innovation strategy.

In the last two decades, CITEVE has taken part in more than 100 R&D projects involving more than European 200 companies, the focus and priorities always being the applicability of results and the acquisition of critical mass. CITEVE has more than 25 IPR's registered, some of them licensed, and a significant number of scientific and technical articles published in various publications.
CITEVE's activity in the field of applied research and technology transfer is also strengthened by its active participation in several networks of excellence, such as: The European Technology Platform For The Future of Textiles and Clothing; Textranet - European Network of Textile Research Organizations; Fashion Competitiveness Pole; Health Cluster Portugal, Forum Manufuture, Oeko-Tex® Association.

CITEVE'S DEFENSE EXPERTISE

CITEVE has been involved in Feasibility Studies of Combat Equipment for Dismounted Soldier (CEDS) funded by the European Defence Agency, such as **ACCLITEXSYS** (Stabilizing body temperature), **ACAMS** (Adaptive camouflage) and **LIVEST** (Lightweight ballistic protection).

ACCLITEXSYS (ACCLImatisation TEXtile SYStem) was focused on military thermal comfort for the development of a smart acclimatisation textile system. Potential active and passive technologies that can act as temperature regulators (heating and cooling), that respond to the soldier's body needs and take into account different environmental conditions were analysed. The most promising were selected for the development of acclimatisation textile systems: Active Fan Cooling, 3D Textile Structures, Thermoelectric Heating/Cooling (Peltier elements) and Heating Elements.

ACAMS (Adaptive CAMouflage for the Soldier) aimed to study methods for camouflage and concealment with adaptation to operating environments and different scenarios. The focus was on avoiding the detection and identification of the soldier by enemy sensors; as well as recognition by electromagnetic radiation at different wavelengths. After analysing different textile technologies, an equipment based on an inflatable and reversible poncho with thermochromics' pigments, adaptive in the visible range and infrared spectrum, was developed as a proof of concept.

LIVEST's (uLtrallgtht weight bulletproof VEST) main objective was to develop a soft ballistic protection with significant Raschel technology 3D structures, in order to reduce weight and minimize the trauma of the impact of a projectile on the user.

Recently CITEVE developed a multicam camouflage pattern and novel uniforms (underwear set, combat uniform, waterproof set, daily uniform) for the Portuguese Army, as well as tactical pack systems (assault rucksacks, hydration system and first aid bag), and boots – among other equipment – using innovative technologies and new materials providing flexibility, comfort, increased protection and other relevant features.

Some on-going projects

European level

STILE is an OB project launched by EDA dedicated to "Smart textiles in defence: looking at the soldiers of the future", aiming at integrating different functionalities related to smart textiles into a single smart combat system.

ACAMS II (Adaptive Camouflage for the Soldier II), follows on from its predecessor, ACAMS, and aims to develop adaptive camouflage to protect the soldier in military conflicts that occur in a multinational context in various types of environments.

VESTLIFE (Ultralight modular bulletproof integral solution) aims to develop a new integral solution: anti-ballistic, lightweight and modular – which includes a CBRN detection system. The protective clothing will present a greater coverage area, maintaining comfort in addition to the ballistic panel's weight reduction, and ensuring the balance between protection and comfort in a modular way to provide the possibility of adapting the protection to the mission's risk.

National level

STRESSENSE (Detection of biomarkers of physical and emotional stress through non-invasive techniques) aims to develop sensors / biosensors for the detection and continuous monitoring of biochemical markers of physical and emotional stress, through a new non-invasive methodology based on electrochemical sensors with advanced technology, allowing its integration in textiles / clothing. It can contribute to the monitoring of the physical and emotional state of individuals, assessing their health, detecting diseases early or contributing to personalised treatments, combining new technologies and new scientific developments to the health area.

AMUT (Advanced Multi-threat Combat System) aims for the development of an advanced multi-threat combat system for the dismounted soldier. This will respond to threats that are emerging in the current context of attacks on built-up areas, namely threats from improvised explosive devices (IED), threats from potentially dangerous objects such as knives, sticks, needles and sharp weapons, as well as providing ballistic protection.

ACAMS II – An Adaptive Camouflage Soldier System

Gilda Santos [1](*), André Barbosa[1], Ana Barros[1], Augusta Silva[1], Isabel Moura[1], Joana Pimenta[2], Duarte Dias [2], Sarah Bogas[2], António Leite[2], Vanessa Miranda[2]

[1] CITEVE – Technological Centre for the Textile and Clothing Industries of Portugal, V. N. Famalicão, Portugal.

[2] CeNTI - Centre for nanotechnology and smart materials, V.N. Famalicão, Portugal

(*)Email: GSantos@citeve.pt

ABSTRACT

The ACAMSII (Adaptive Camouflage for the Soldier II) project is implemented under the Preparatory Action on Defence Research (PADR), as a grant for the Research Action call on the topic of Force protection and advanced soldier systems beyond current programmes, on subtopic Adaptive Camouflage. The project led by Totalförsvarets forskningsinstitut (FOI) – Sweden has a consortium that encompasses 6 other participants from 5 countries, namely, CITEVE and DAMEL (Portugal), IOSB (Germany), FTMC (Lithuania), TNO (The Netherlands) and SAFRAN (France).

The project envisages to develop adaptive camouflage for soldier protection in future military conflicts occurring in a multinational context in various environments including dynamic changes. An advanced opponent might operate sensors in several wavelength bands and use sensor data fusion in order to extract further information. This new threat situation creates a strong need for multispectral adaptive camouflage for the soldier.

INTRODUCTION

ACAMSII aims to integrate several active and passive adaptation mechanisms into a textile-based soldier camouflage system. It will address several wavelengths bands, such as visual, near infrared, short wave infrared, thermal infrared and radar. Military needs on sensing, fire power, mobility and endurance are considered.

The reduction in detection range and hence the increase in survivability will be assessed using both well-established methods and new methods to capture the adaptive properties. The dialogue with military end-users starts early in the project to set requirements and continue throughout the project to ensure relevance.

The activities of this project include:

- Survey of present and future advanced threat sensors and sensor systems in military relevant bands of the electromagnetic spectrum (visible, near infrared, short wave infrared, thermal infrared and radar)
- Study of relevant missions for EU military forces
- Research and development of advanced materials, structures, mechanisms, methods and components for adaptive and passive camouflage
- Verification of the adaptive camouflage performance by lab measurements
- Development of a camouflage concept in the lab and validation in a relevant environment
- Dissemination of the results to a military, academic and industrial audience
- Exploitation of information to national military equipment, procurement agencies and armed forces.

RESULTS AND CONCLUSIONS

The ambition of the project is to reduce the soldier signature and hence increase its survivability and operability. To achieve this goal, specific technologies are applied in the prototypes:

- Adaptation in several wavelengths bands by combining active components in several wavelength ranges
- Researching combination of IR signature reduction and radar absorption of conductive polymer structures
- Integrating VIS and NIR diodes (multiband camouflage) into a clothing system
- Using a pattern generation algorithm to get adaption to e. g. an urban environment
- Considering radar camouflage for soldiers, which has not been done before, despite the escalation of battlefield radar employment, usually operating at approximately 8-40 GHz. A threat evaluation of such radar systems will be performed.

From several proposed architecture approaches, two were selected, comprising adaptive camouflage mechanisms, namely thermochromics, LEDs and PCMs, among others to achieve multispectral signature management. A tri-layer system was conceived and is comprised by inner layer (underwear), middle layer (combat uniform) and outer layer (adaptive camouflage system). ACAMSII overall concept in different environments and adaptation mechanisms are presented in Figure 1.

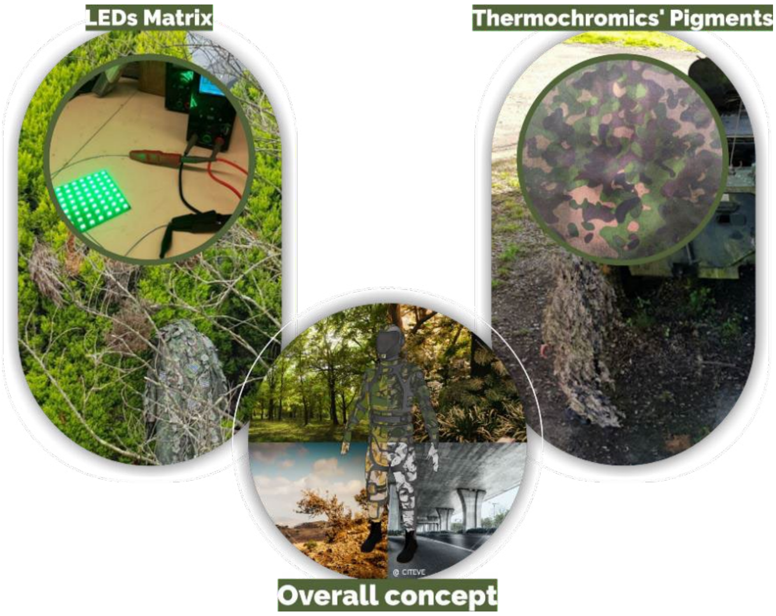

Fig. 1 ACAMSII overall concept in different environments and adaptation mechanisms

Research and development studies were performed using an end-user centred design methodology. Several designs were materialised in proofs of concept, where in each iteration feedback from military users (PT army) provided inputs that served as bases for enhancements and improvements towards the final solutions.

ACKNOWLEDGMENTS

The authors would like to express their appreciation for the support of the sponsors [European Union's Preparatory Action on Defence Research - PADR programme under grant agreement No 800871].

AMUT – An advanced Multi-threat Combat System

Gilda Santos[1](*), André Barbosa[1], José Borges[2], Lopes Polho[2], Pedro Pinto[3], Igor Ribeiro[3]

[1] CITEVE – Technological Centre for the Textile and Clothing Industries of Portugal, V. N. Famalicão, Portugal.

[2] CINAMIL- Centro de Investigação, Desenvolvimento e Inovação da Academia Militar, Academia Militar, Instituto Universitário Militar, Lisboa, Portugal

[3] POLYANSWER-Possible Answer S.A., Braga, Portugal

(*)Email: GSantos@citeve.pt

ABSTRACT

The ever-evolving phenomena of terrorism and conflicts, especially in urban environments, is characterised by modern capabilities such as new technologies of warfare and precision, allied with traditional methods such as sieges, tunnels, explosive traps, artillery, mortars and snipers. In effect, improvised explosive devices (IEDs), potentially dangerous objects such as knives, batons, needles and sharp and bulletproof weapons, make it imperative to develop an advanced multi-threat combat system for the dismounted soldier. The needs of the soldier must be solved taking into account their real requirements in different scenarios. This project has a duration of 36 months and aims to improve and develop an advanced clothing system using innovative technologies and new materials to protect the soldier from the multi-threats linked to the conflicts of the actual and future operational theatres. CINAMIL leads the consortium of the AMUT project, which is also integrated by CITEVE and POLYANSWER.

INTRODUCTION

Protective clothing is a key element in contributing to the achievement of the levels of protection and comfort - as well as quality of life - which are required today. The objectives of the AMUT project are the development of advanced textile materials to increase multi-threat protection (shattering, impact, cutting, stab, drilling and ballistic projection) and performance (mechanical strength, breathability, comfort flexibility, modularity, lightness and ease of cleaning and maintenance) that will be integrated into a global architecture to provide multi-layer protection, ergonomics, comfort, functionality and overall durability. In addition, the study of aesthetics and corporate image is to be undertaken. Furthermore, the project aims to improve the user's military performance and contribute to the increase of the duration of military missions.

The methodology to be adopted consists of an interactive, articulated and dynamic work plan, consisting of 7 main activities, organised over 36 months. To that effect, a study was first performed regarding the needs of the military users, the available products on the market, the existing norms and legislation (both for textiles and military area) and the most experienced theatre of operation environments.

RESULTS AND CONCLUSIONS

Taking into account the information gathered regarding the necessary protections and body mapping critical zones, a two-layered system design was proposed consisting of an inner layer (underwear shirt and trousers) and an outer layer comprised of camouflaged printed overalls. The inner layer provides thermal comfort and localised impact protection, as well as perforation and slash resistance. The outer layer was designed to provide heat and flame protection, tear protection and ballistic protection localised at the shoulders and upper trunk area. Figure 1 depicts the design of the two layers, an initial (left) and final proposal (middle) for the underwear, and the camouflaged overall (right).

Fig. 1 Design of the AMUT two-layer system

A mock-up of the inner layer was developed to evaluate the most suitable shapes and forms for the textile integration of the several protection materials and the most appropriate technologies for the process. The first proof of concept was then fabricated and subjected to preliminary ergonomic and comfort evaluation for further improvement, culminating in the second proof of concept. Some improvements in the development of the inner layer are depicted in Figure 2.

Fig. 2 Inner Layer evolution process

Regarding the outer layer (the camouflaged overall), a first proof of concept was developed, and after functional, ergonomic and comfort assessment, a second proof of concept was fabricated (Figure 3).

Fig. 3 Outer Layer second proof of concept

The two-layer system is currently under evaluation by military end-users, whose feedback of the functional, ergonomic and comfort properties will provide valuable information to improve the current proofs of concept. Further evaluation will be performed with military end-users in a real environment, including field tests and operation context, and performance evaluations in laboratory tests.

ACKNOWLEDGMENTS

This study was made possible thanks to a team of Portuguese partners (CINAMIL, CITEVE and POLYANSWER) integrating this R&D PT Army project in the area of Security and Defence Support Technologies.

Stress sensing based on sweat biomarker analysis for integration in textiles - The Stressense Project

Gilda Santos[1](*), M. João Nunes[2], Gabriel N. Valério[2], Alejandro Samhan-Arias[3], Ludwig Krippahl[4], José J. G. Moura[2], João P. Sousa[5], Carlos Rouco[5], Cristina M. Cordas[2](*)

[1] CITEVE, Centro Tecnológico das Indústrias Têxtil e do Vestuário de Portugal, Rua Fernando Mesquita, nº 2785,4760-034 Vila Nova de Famalicão, Portugal

[2] LAQV, REQUIMTE, NOVA School of Science and Technology, FCT NOVA, Universidade Nova de Lisboa, Campus de Caparica, 2829-516, Portugal

[3] Departamento de Bioquímica, Universidad Autónoma de Madrid e Instituto de Investigaciones Biomédicas 'Alberto Sols' (CSIC-UAM). C / Arturo Duperier 4, 28029-Madrid, Spain

[4] NOVA-LINCS, Departamento de Informática, Faculdade de Ciências e Tecnologia, NOVA, 2829-516 Caparica, Portugal

[5] CINAMIL, Academia Militar, Rua Gomes Freire, 1150-244 Lisboa, Portugal

(*)Emails: gsantos@citeve.pt, cristina.cordas@fct.unl.pt

ABSTRACT

Stress, both physical and psychological, is related to several diseases and discordant social behavior. In the STRESSENSE project, funded by Fundação para a Ciência e Tecnologia, civilian, military and business association researchers (from FCT-NOVA, CINAMIL/Academia Militar and CITEVE) join their multidisciplinary skills to attain a novel methodology for early stress biomarker detection, using non-invasive methodologies applied to sweat as the target biological fluid. The goal is to attain an integrated sensor in wearables. The team has complementary expertise in electrochemistry, analytics, biochemistry, materials, smart textiles, data-processing, and machine learning, together with knowledge associated to the emotional and physical behaviour of individuals. Volunteers from the Portuguese Army (Academia Militar) take part in this case-study, novel methodology and proof-of-concept. The innovative sensing wearable textile device, in development, presents high interest in different fields from medicine, to sports or healthcare services.

INTRODUCTION

The detection of biomarkers is an important field of research [1] since allows the development of new methods and devices with interest in medicine, amongst other areas. Less invasive methods using sweat or saliva have been pursued. In the current project, from the direct sweat analysis, the detection and monitoring of stress biomarkers is pursued for a textile fabric integrated sensor development. An initial method was developed for the stress biomarkers detection in sweat (stress and rest conditions) by classic analytical methods (e.g. LC-MSMS) for the identification of potential molecules.

Electrochemical techniques (CV and DPV), were used to attain the redox properties of such molecules and its variations in stress and rest conditions. A correlation between sweat and blood analysis of the attained biomarkers was attained, enabling the identification of a set of molecules that will be integrated in textile fabrics and used for sensor development.

RESULTS AND CONCLUSIONS

A novel methodology for the rapid identification of molecules present in the sweat samples (collected in rest and physical stress conditions from young healthy Cadets from the "Academia Militar" of the Portuguese Army), was developed using ultra high-performance liquid chromatography (UHPLC) coupled with multiple-reaction monitoring (MRM) tandem mass spectrometry (LC-MSMS) allowing for the identification of 26 potential stress biomarkers [2]. From the 26 identified molecules some were already stress related biomarkers, such as epinephrine or cortisol. The major potential identified biomarkers are neurotransmitters (NTs) and other molecules, such as amino acids and steroid hormones. All the identified biomarkers were electrochemically characterized using CV and DPV techniques on disposable carbon screen-printed electrodes (modified with carbon nanotubes), as the real samples. Comparing the results observed in sweat with the results achieved from blood through clinical analysis (made by certified laboratories), correlations between the levels' variations of several molecules were found. In particular, for a set of 6 potential biomarkers, a good correlation was achieved, namely, dopamine (DA), serotonin (5-HT), tryptophan (Tryp), tyrosine (Tyr), phenylalanine (Phe) and Cortisol (Cor). Different fabrics, unmodified and modified with printed conductive carbon ink (with and without a ultimate carbon nanotube layer) were tested using simulated sweat, with special attention to their electrochemical response and possible interferent. NOTE: A written consent from the participating volunteers was previously attained. The study was performed in compliance with the ethical standards (World Medical Association, Declaration of Helsinki) and was approved by the ethics committee of Universidade Nova de Lisboa and the Portuguese Army.

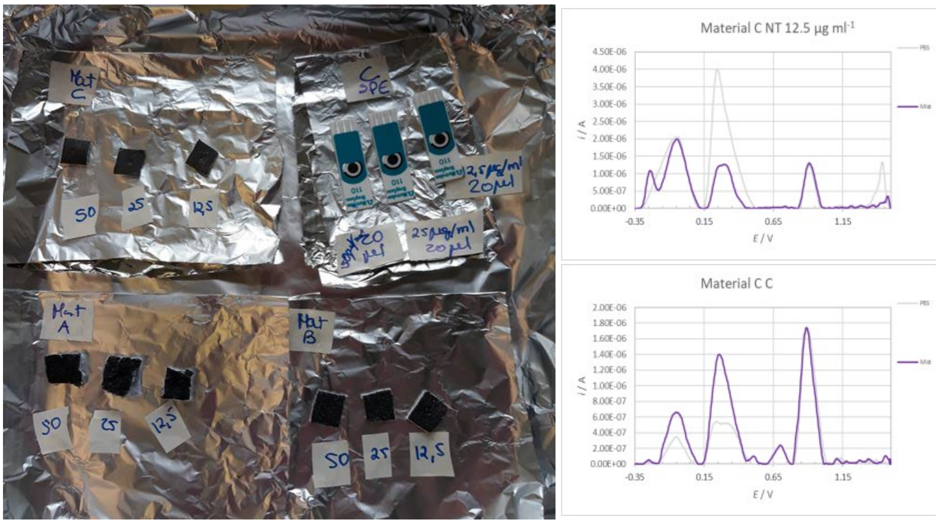

Fig. 1

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REFERENCES

1. Jia, M.; Chew, W. M.; Feinstein, Y.; Skeath, P.; Sternberg, E. M., *Quantification of cortisol in human eccrine sweat by liquid chromatography – tandem mass spectrometry,* Analyst, 2016, 141, 2053-2060.
2. Nunes, M.J., Cordas, C.M., Moura, J.J.G., Noronha, J. P., Branco, L. C. Noronha, Luís Branco, *Screening of Potential Stress Biomarkers in Sweat Associated with Sports Training, Sports Medicine* – Open, 2021, 7:8, 1-9.

SmarText4EStore: Smart Textiles for Energy Storage

Gilda Santos[1](*), Rui S. Costa[2,3], Joana S. Teixeira[2,3], Gabriela Queirós[2], S. Maryam Sadeghi[3], Ana L. Pires[3], Natalia Rey-Raap[4], Olívia S. G. P. Soares[4], José Morgado[1], M. Fernando R. Pereira[4], André M. Pereira[3], Clara Pereira[2]

[1] CITEVE - Technological Centre for the Textile and Clothing Industry of Portugal, 4760-034 Vila Nova de Famalicão, Portugal

[2] REQUIMTE/LAQV, Department of Chemistry and Biochemistry, Faculty of Sciences of University of Porto (FCUP), 4169-007 Porto, Portugal

[3] IFIMUP, Institute of Physics for Advanced Materials, Nanotechnology and Photonics, Department of Physics and Astronomy, FCUP, 4169-007 Porto, Portugal

[4] LSRE-LCM, Department of Chemical Engineering, Faculty of Engineering of University of Porto (FEUP), 4200-465 Porto, Portugal

(*)Email: gsantos@citeve.pt

ABSTRACT

The development of clean energy storage technologies has been a global concern to address the ever increasing energy demand and depletion of non-renewable energy sources. With the global proliferation of wearable electronics, new market opportunities have arisen regarding the production of the next-generation of energy storage clothing. Supercapacitors are a safe and eco-friendly energy storage solution for wearable energy storage, with promising prospects for Medicine, Healthcare, Fashion and Military applications to power smart sensors, flexible displays, lightning and tracking systems.The R&TD project SmarText4Estore envisages the production of a new generation of hybrid textile supercapacitors featuring enhanced performance, flexibility, lightness, safety and long lifetime. Several strategies are being pursued starting from textile electrodes design and use of eco-friendly electrolytes, to engineered design of new textile supercapacitor configurations and scalable cost-effective fabrication processes.

INTRODUCTION

With the proliferation of high-tech portable electronics, wearable energy storage technologies became a major target, with vital importance for medical, military and consumer applications [1]. The self-powered smart garments available in the market rely on non-flexible Li-ion batteries. Despite having a high energy density, they face major limitations concerning their toxicity, safety, cycle life and high (re)charge time [1].

Supercapacitors (SCs) are a promising energy storage technology, due to their high-power density, fast charging times, long lifecycle and low maintenance cost [1]. This boosted the development of lightweight and flexible SCs that can be integrated in textiles. Nanotechnology fostered innovation on flexible/wearable energy storage textiles, while preserving the fabrics' comfort and lightness [2].

SmarText4EStore - Smart Textiles for Energy Storage is an ongoing R&TD project funded by the Portuguese funding agency (Fundação para a Ciência e a Tecnologia, FCT/MCTES) since 2018. This multidisciplinary project is coordinated by the Associate Laboratory REQUIMTE/LAQV@FCUP, in collaboration with two R&D units – IFIMUP@FCUP and LSRE-LCM@FEUP – and the Technological Centre for the Textile and Clothing Industry of Portugal (CITEVE). In this project, textile supercapacitors (TSCs) based on innovative hybrid/doped carbon-based nanomaterials featuring enhanced electrochemical performance, are being developed through scalable eco-friendly processes [2,3]. Other flexible substrates are being tested, namely paper and flexible plastics [4]. More recently, an advanced two-in-one energy harvesting and storage technology was developed for textiles and flexible plastic [5,6]. This technology is able to harvest waste thermal heat released from low-grade heat sources and convert it into electrical energy, which is stored within the same device.

RESULTS AND CONCLUSIONS

All-solid-state TSCs based on cotton fabrics coated with industrial-grade MWCNTs and a safe polyelectrolyte were produced with different active areas (2–8 cm^2) through an eco-friendly scalable dippad-dry process.[3] The performance was tuned by changing the device area: the largest TSC presented the highest energy density (E) of 6.30 Wh kg^{-1}, which was 14× higher than those of other carbon-based TSCs reported in literature. The smallest TSC afforded the highest power density (P) of 2.72 kW kg^{-1}, being 49× higher than those of comparable systems. The TSCs presented excellent cyclability (96% for 5000 charge/discharge cycles). Finally, a sensor was powered for 47 min by coupling two TSCs in series (14 cm^2). This work demonstrated the ability to produce efficient TSCs using industrial grade MWCNTs by processes implemented in the textile industry.

This work is being extended to tailor-made nanomaterials including oxidized/doped and hybrid carbon/metal oxide nanomaterials. Multifunctional TSCs merging energy storage and fluorescent properties were developed, featuring excellent cycling stability (100% for up to 10000 cycles) and intense fluorescent colours under UV light irradiation.

Fig. 1 features highlighted representative photographs illustrating the fabrication of TSCs by dyeing and screen-printing, as well as their real performance to power sensors and LED lightning systems.

Fig. 1 – TSCs fabrication and real performance to power sensors and LED lightning systems.

Other types of substrates are being used for the development of flexible SCs, namely flexible plastic and paper. Multifunctional hybrid nanomaterials of N-doped CNTs functionalised with ferrite nanoparticles (CNT-N@X, X=$MnFe_2O_4$, Fe_3O_4, $CoFe_2O_4$) were prepared and tested as electrode nanomaterials in all-solid state paper SCs [4]. The devices presented synergistically-enhanced energy storage properties and high cycling stability, affording up to 11.1× higher volumetric E and up to 5.2× higher volumetric P than other carbon-based paper SCs reported in literature.

Recently, a self-powered dual-function thermal energy harvesting & storage technology was developed on flexible plastic and textile substrates (Fig. 2) [5,6]. This multi-tasking technology is able to simultaneously capture thermal energy released from low-grade heat sources (e.g. human metabolism), convert it into electrical energy, which is then stored within the same device. This technology is a promising advance in the field of flexible/wearable electronics for low-grade applications towards the next-generation of self-powered devices.

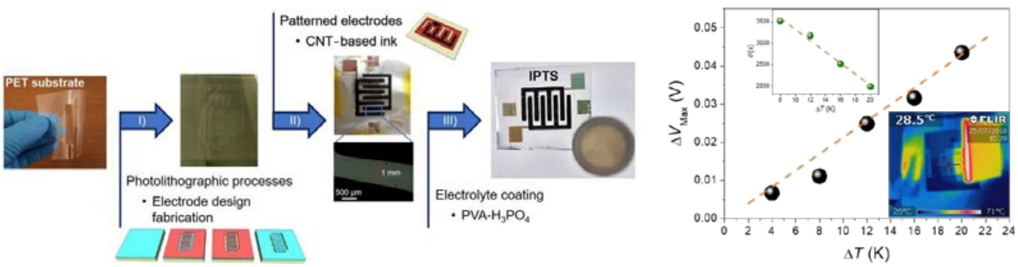

Fig. 2 – Planar energy harvesting & storage plastic-based technology.

ACKNOWLEDGMENTS

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REFERENCES

1. Z. Zhang, C. Jiang, J. Liang, W. Wu. *Electrode materials and device architecture strategies for flexible supercapacitors in wearable energy storage,* J. Mater. Chem. A, 2021, 9, 8099–8128.
2. C. Freire, C. Pereira, A. F. Peixoto, D. M. Fernandes, B. Jarrais, M. Nunes, R. Ramos, *Hybrid/Doped Carbon-Based (Nano)materials for Advanced Applications: Eco-Sustainable Catalysis, Biomass Valorization, Energy Technologies & Smart Devices,* Bol. Grupo Español Carbón 2019, 54, 12–26.
3. R. S. Costa, A. Guedes, A. M. Pereira, C. Pereira. *Fabrication of all-solid-state textile supercapacitors based on industrial-grade multi-walled carbon nanotubes for enhanced energy storage, J*. Mater. Sci., 2020, 55, 10121–10141.
4. C. Pereira, R. S. Costa, L. Lopes, B. Bachiller-Baeza, I. Rodríguez-Ramos, A. Guerrero-Ruiz, P. B. Tavares, C. Freire, A. M. Pereira. *Multifunctional mixed valence N-doped CNT@MFe2O4 hybrid nanomaterials: from engineered one-pot coprecipitation to application in energy storage paper supercapacitors,* Nanoscale, 2018, 10, 12820–12840.
5. A. L. Pires, R. S. Costa, C. Pereira, A. M. Pereira. *An Interdigital Planar Energy Harvesting/Storage Device Based On an Ionic Solid–Gel Polymer,* ACS Appl. Electron. Mater. 2021, 3, 696–703.
6. A. M. Pereira, C. Pereira, A. L. Pires, R. S. Costa, Patent WO2020065533 - *Thermionic Capacitor Chargeable by Soret-Effect using a Gradient Temperature,* 2020.

Presentation of Europa Victrix

Philippe Atgé
Europa Victrix
Email: evictrix@europavictrix.com

ABSTRACT

Europa Victrix is a Portuguese company, created in 2018 and based in Portugal. The activities of the company are divided into two categories: those of the services and those related to products. As for the products, Europa Victrix features ballistic vests and medical clothing. As for the services, Europa Victrix offers consultancy in the domain of international security, more specifically in the field of defence economics.
Up to now, Europa Victrix has become a partner of several Portuguese and other European enterprises and organisations in the fields of health and defence. Logically, this has been achieved by providing the equipments these organisations need, but also through the sponsoring of events, such as congresses aimed at sharing knowledge within these same fields.

The products that the company presents are manufactured in Portugal and are exclusively made from materials from European industries (mainly Portugal, Italy and Greece).
The company has conducted a series of tests with the Spanish textile institute Aitex for the development of the ballistic properties of its bullet-resistant insert panels.
Since May 2021, Europa Victrix has become an associate of the Portuguese Chamber of Commerce and Industry.

The Future Soldier

Günter Grabher
CEO, Grabher-Group GmbH
Email: g.grabher@tgg.at

ABSTRACT

The Grabher Group is a leading manufacturer of high-tech products. As manufacturer of technical textiles, we are always looking for new challenges. Our core competencies are in the production of filter media, and technical and smart textiles. We are as diverse as the material we work with. We offer special solutions in the fields of medicine & hygiene, air and liquid filtration, smart textiles, nanotechnologies and lightweight composite materials.

INTRODUCTION

The competence of Grabher-Group for the modern soldiers of the future tackles new technologies such as smart textiles fibre composites and nano technology. Through our expertise the soldier is protected and supported in his daily business.

RESULTS AND CONCLUSIONS

- Vital data monitoring with textile electrodes.
- Textile shoe sensor for pressure detection (mine warning system).
- Plasma coatings for fire and waterproof equipment.
- Nanoparticle for the change of colour implemented in a garment.
- False identification by active heating textiles

Fig. 1 The Future Soldier

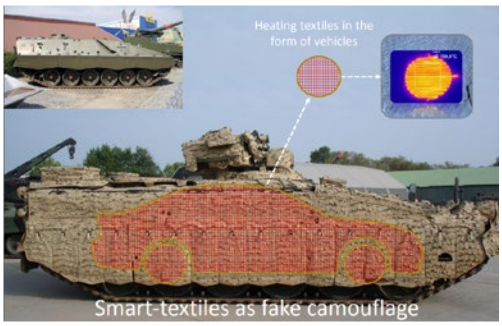


Fig. 2 False identification

- Tailored fibre placement

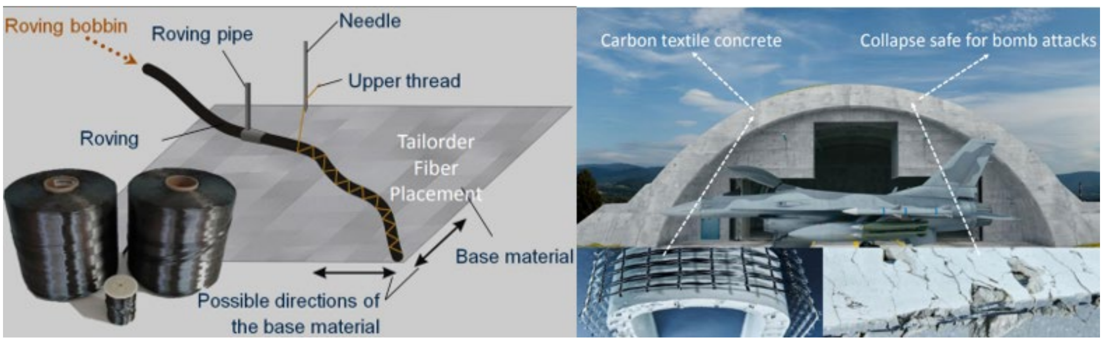


Fig. 3 Carbon textile

Powering smart textiles with artificial intelligence for assessing physical fatigue, injury prevention and stress detection

Sergio Luengo-Sanchez, Marco Benjumeda, Gaizka San Vicente(*)
Olocip 11 SL, Madrid, Spain
(*)Email: gsanvicente@olocip.com

ABSTRACT

Smart textiles can integrate multiple sensors that monitor the user and the environment. The next generation of smart textiles aims to exploit this information to create garments that react and adapt to different scenarios and contexts. In this field, artificial intelligence plays a key role as a cognitive engine that interacts with the users, monitors their state and alerts about risks. This approach opens the door to new applications in the military and sports industries through performance optimisation, stress level monitoring, or injury prevention, among others.

INTRODUCTION

Smart textiles have evolved significantly in recent years. In part, this development has consisted of integrating more sensors in order to measure different aspects of the state of the users and their environment [1], generating large amounts of data. Analysing this volume of information and combining the multivariate data generated by the sensors - preferably in real time - requires autonomous intelligent systems. Thus, the next generation of smart textiles [2] aims to exploit this data reacting to environmental stimuli. Artificial Intelligence (AI) is essential in order to implement cognitive engines capable of interpreting sensor measurements and providing context-specific responses. This approach offers new possibilities for the physical and mental training of military personnel and elite athletes.

One of the most straightforward applications of this technology in both the military and sports industries is performance monitoring. Heart and respiratory rates, electrodermal activity, and muscle responses are good indicators of physical workload and fatigue. However, in order to determine the subject's fitness level, it is necessary to contextualise these measurements within the type of activity the user is performing. The real world is an open environment in which different types of activity are interspersed without planning, making it difficult to establish a direct relationship between the activity and the fatigue level or injury risk beforehand. Fortunately, AI systems embedded in smart textiles are capable of automatically classifying different physical activities [3] in real time. By combining information such as effort and activity, the AI system can alert the user about unusual situations that may involve physical risk or result in an injury [4]. Moreover, AI techniques can be used to analyse the data generated during the training session, providing insight on how to optimise workouts and diagnose health problems faster and more accurately [5].

Furthermore, physical and mental health are crucial to achieve a better performance under stressful conditions. Sustained high levels of stress may have a negative impact on the performance of the motor system and affect decision-making processes, putting the person at risk. Therefore, there is an increasing interest in developing advanced technologies based on AI and smart textiles to measure workload, stress and fatigue in order to improve performance under stressful situations, prevent injuries and optimise training sessions. These strategies have a great potential, even in stress monitoring, since there are many physiological reactions measurable by smart textiles that can be integrated in complex AI systems [6,7].

RESULTS AND CONCLUSIONS

Olocip is a pioneering company in the application of AI in sports. Its solutions include modelling the performance of elite athletes, the contextualisation of players and coaches within new scenarios, and the development of sensory systems based on computer vision. Thus, the company has extensive experience working with sensorial data, and has developed complex AI systems that learn patterns from signals obtained from multiple sources, such as GPS tracking systems, blood tests, accelerometers, electrocardiograms and rates of perceived exhaustion, in order to characterise the types of workouts performed by the players and to assess their risk of injury.

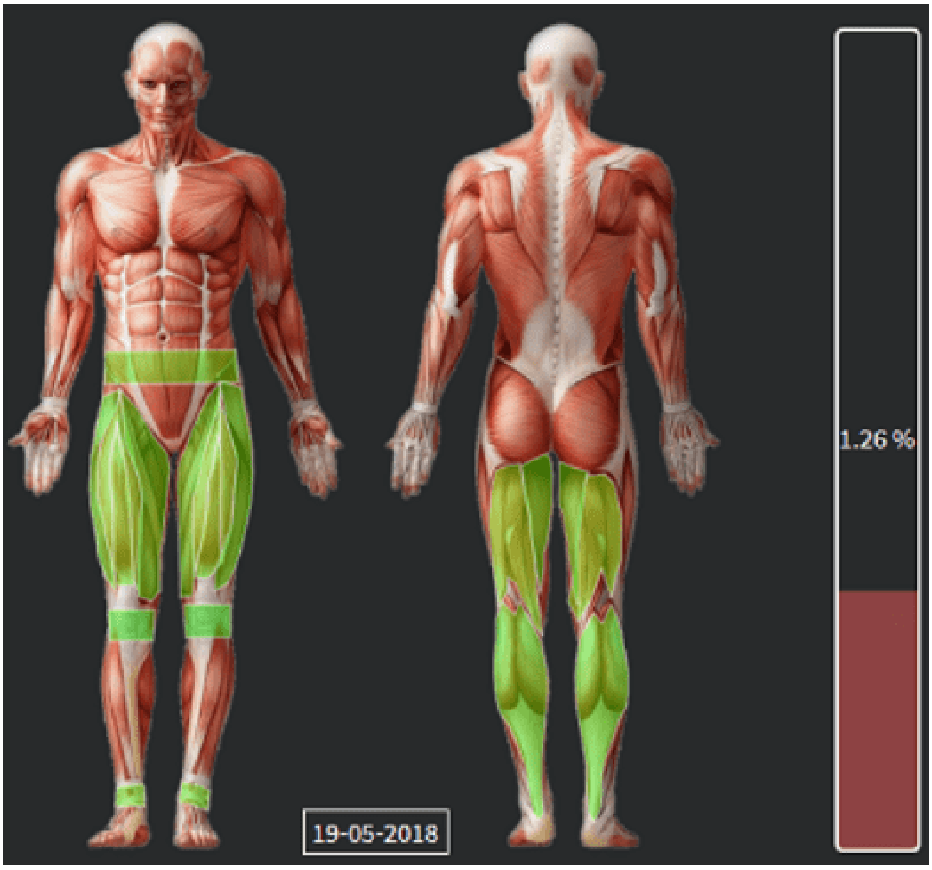


Fig.1 Risk of injury of a player for each body part. The risk of injury is induced by an AI model that processes sensorialdata of the athlete.

Another example, in which Olocip uses AI to extract deep insight, is on physical performance in tennis. In this project the input is a video recording of a match or training session and, with just that information, the system extracts many important features such as the actions performed by the players (e.g., forehand, backhand and volley), and their physical effort evaluated through various parameters, such as distance travelled, speed, acceleration, strength of the strokes.

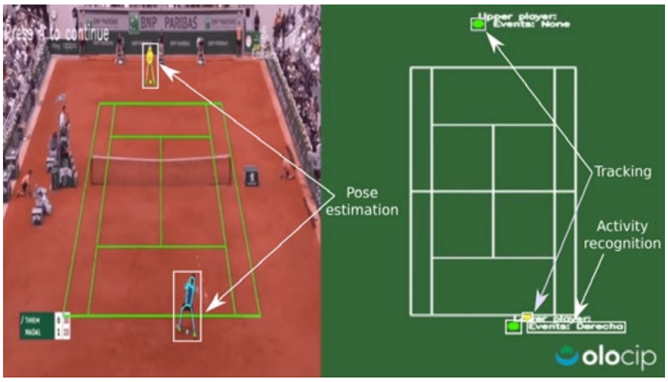


Fig. 2. Olocip's AI-based optical tracking system. This system tracks the location of the players and the ball and detects the actions performed by the players from the video signal

Both projects implement AI systems that transform multiple raw signals into features that describe the context, classify the types of actions and activities performed by the players automatically, and estimate their physical effort. Some of our input signals come from smart textiles and, in the near future, we hope that the system will be benefited by the incorporation of new sensors to sportsware.

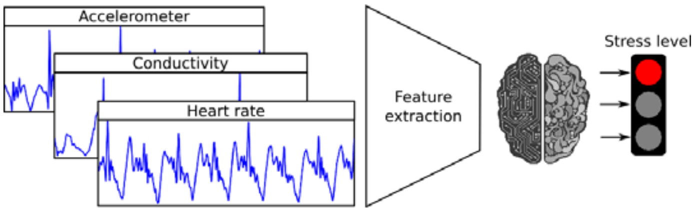


Fig. 3. Architecture of a stress detection system based on AI

At present, Olocip is involved in a project that aims to avoid high stress levels in which the physical and mental state may result in a hazardous situation. The objective is to predict the probability of surpassing a certain stress threshold and provide the necessary time to make decisions focused on reducing the risk. This type of strategy can be crucial both in civil and military environments.

In conclusion, smart textiles have a great potential to generate multiple types of data and AI can work with them to offer smart solutions to optimise performance and reduce risks.

REFERENCES

1. Angelucci, A., Cavicchioli, M., Cintorrino, I. A., Lauricella, G., Rossi, C., Strati, S., & Aliverti, *A. Smart textiles and sensorized garments for physiological monitoring: A review of available solutions and techniques.* Sensors, 2021, 21(3), 814.
2. Çelikel, D. C. *Smart E-Textile Materials,* In: Advanced Functional Materials, IntechOpen, Rijeka, 2020.
3. Mokhlespour Esfahani, M. I. & Nussbaum, M. A. Classifying Diverse Physical Activities Using "Smart Garments", Sensors, 2019, 19(14), 3133.
4. Van Eetvelde, H., Mendonça, L. D., Ley, C., Seil, R., & Tischer, T. *Machine learning methods in sport injury prediction and prevention: a systematic review.* Journal of Experimental Orthopaedics, 2021, 8(1), pp. 1-15.
5. Al-Turjman, F., & Baali, I. *Machine learning for wearable IoT-based applications: A survey,* Transactions on Emerging Telecommunications Technologies, 2019, e3635.
6. Kim, H. G., Cheon, E. J., Bai, D. S., Lee, Y. H., & Koo, B. H. Stress and Heart Rate Variability: *A Meta-Analysis and Review of the Literature.* Psychiatry investigation, 2018, 15(3), 235.
7. Panicker, S. S., & Gayathri, P. *A survey of machine learning techniques in physiology based mental stress detection systems.* Biocybernetics and Biomedical Engineering, 2019, 39(2), pp. 444-469.
8. Olocip, from https://olocip.com/

Foldable, built-in command panel in intelligent clothing for soldiers

Papp István
Pier Technology Ltd. ,Thriveo Central Europe Ltd.
Email: istvan.papp@878co.com

ABSTRACT

Our consortia are specialized on designing and producing intelligent garments in the area of professional sport, healthcare and defence.

The Pier and Thriveo digital soldier communication system improves communication and combat capability by giving soldiers information access on the ground. The solution is in a prototyping phase. Field-tests and battle-readiness for pilots are to come.

The Pier and Thriveo embedded foldable screen enables group and one-to-one communication and real-time messaging so soldiers can react faster and on a more coordinated way. Integrated with field communication systems via standard interfaces, a simple foldable screen provides improved tactical and strategic decision-making opportunities, increased capabilities and agility, resulting in fewer casualties.

The system can be deployed tactically for special operations, fire support, convoy protection and sensitive sites protection.

INTRODUCTION

Defence operations these days faces a new set of challenges: conflicts are on the rise and constant information availability is key.

In this new age, every defence decision needs to consider the following criteria: collaboration in combat, mixed reality soldier, tactical communications, data availability, and security.

Pier and Thriveo in Central-Europe are exploring new and innovative solutions within the area of intelligent military clothing with embedded systems.

The adoption of intelligent combat clothing demonstrates how new technologies can enhance information provided to soldiers about their surroundings in order to enable them to do something that was previously not possible. Tactical communications are evolving by the usage of LTE/4G capabilities and secure communications with new types of devices in surveillance and combat operations.

The E-ink foldable screen, embedded into the military-grade tactical gear is a true enabler. It is an ultralight solution which results in no limitation for the soldier when executing special tasks during a mission. The screen with foldable electronics is securely integrated into the fabric of the tactical gear and connects to all kinds of communication devices via secure and wireless communication.

Power supply can be provided by either a foldable solar panel placed on the jacket or an ultralight lithium battery with 8-10 hours run time.

At this stage, screen data can be refreshed twice per second, but it can be increased up to 10-12 times per second.

With a small, embedded antenna, GPS coordinates of the soldier can be provided for improved communication and additional accuracy of commands.

The solution is capable of handling endless amounts of data coming from different sensors or systems. By setting multiple pages on the panel (3 data points per page), soldiers can have access to all important commands and combat information without limitations. Each panel can be configured individually, given the set of data required by the soldiers.

RESULTS AND CONCLUSIONS

With a simple, cost-effective and enabling military grade solution, Pier and Thriveo can improve communication significantly without adding additional weight or limitations for soldiers. Our solution was developed for professional sports which, with necessary modification, can be made field-ready.

The total cost of the solution is between 300-450 EUR per panel with printed or foldable electronics.

ACKNOWLEDGMENTS

We would like to recognize our partner, Plastic Logic Inc. for developing the E-ink panel and for working with us and our customers to redesign and make it military-grade and field ready. This partnership is vital in providing leading solutions to defence organizations.

We also acknowledge the Modernization Institute of Hungarian Military, who is building an effective ecosystem of innovative companies and encouraging world class innovation in a country with a rich history and great ambitions in the defence industry.

Dual use developments in defence and textile

Stefano Carosio[1](*), Bruno Conterno[2], Giulia Barbagelata[3], Julie Rafton-Jolivet[4]

[1] Stam srl, [2] SIIT Scpa, [3] SIIT Scpa, [4] TECHTERA

(*)Email: s.carosio@stamtech.com

ABSTRACT

Smart textiles are a disruptive topic that can find applications in several sectors such as health and well-being, cars and vehicles, and military and security, to name a few. Since the launch of space programmes, smart textiles are finding applications in astronauts' suits and are gathering attention for the future of manned space exploration. When it comes to the defence sector, there are several programmes funded at national and international scale, as well as technology roadmaps that identify actions expected in the near future regarding support in the battlefield, patrolling and peace keeping operations. According to this framework, this abstract summarises the work under development within SIIT in the framework of the ALLIANCE and EU-ALLIANCE project, with the support of one of its members, Stam. This activity is instrumental to identify common areas of interest between defence and industrial sectors in order to foster dual use developments, cross sectoral collaborations and SMEs internationalization. The methodology is based on a top-down and bottom-up approach aimed at exploring all strategic research and innovation roadmaps and studies being developed by international agencies and organisations as well as an in-depth review of patents and publications that may identify collaborative networks, including innovative start-ups and research teams. The ultimate goal is to cluster the main opportunity areas with a high potential for dual use developments and identify all relevant on-going initiatives which may trigger mutual exchanges by smart textile companies, and defence business that may trigger innovative products and services for the future.

INTRODUCTION

Smart Textiles are multifunctional materials and systems which consist in a seamless integration of sensing and actuating functionalities within a textile web or patch. This may include energy harvesting for self-powering, changing colours and porosity, for instance, thus enabling smart filters, camouflage etc. Indeed, their high potential for being integrated into uniforms and platforms have drawn the attention of defence stakeholders in the last decades. This goes along large efforts that are placed by the textile industry in collaboration with electronics and ICT players to move from the first generation of smart textile solutions to smoothly integrated systems that can be easily integrated for medical applications, smart automotive interiors, and many other industrial applications. In this framework, there is a high potential for collaboration between defence and industrial business in order to foster dual use technologies that can benefit both sectors, while ensuring a critical mass of resources, and efforts being mobilised to solve functional challenges of common interest.

Defence applications are peculiar in terms of requirements; therefore in order to identify all promising areas for collaboration our goal is, on one hand, to explore the large scenario of strategic research and innovation roadmaps – including, for instance, the European Defence Agency Strategic Research Agenda of the Materials CapTech – and on the other hand, the patents, scientific publications and landscape of emerging products and collaborative networks, including start-ups. This allows to identify and cluster major findings in common interest areas for both the defence and textile industry, which properly connect the stakeholders around joint priority areas through participation in events, workshops and brainstorming sessions. In this respect, the EU-ALLIANCE project represents a unique opportunity to proactively create new business opportunities within the umbrella of the European Textile Technology Platform and to foster cooperation and internationalisation among SMEs. This work leverage on the methodology developed by Stam: on one hand it analyses patents and papers, market trends, geographical scenarios, key players and start-ups through keywords and queries from available taxonomies (e.g. Staccato) and domain expertise; on the other hand, it engages experts and practitioners in the following review of the draft roadmap with clustered priorities. The opportunity to set priorities based on the dual use potential is enabled by this proprietary methodology to identify critical technologies which can address the theme of Technology Sovereignty as a key political driving force when focusing future technology developments in critical areas such as smart textiles.

RESULTS AND CONCLUSIONS

Based on some focused analyses in the field of protective suites and gears applied to space, defence and civil applications, we have identified thermal management as a key and cross-cutting topic. In this framework, the management of heat flows addressing the challenge of heat accumulation when using vapour permeable membranes or textile composite systems emerged as a key area for patents and scientific literature and emerging businesses. Another key area is textronics which includes fibrous detectors, embedded systems and automatic control systems for protecting people, monitoring health conditions and signalling hazards. Another area is nanotechnology and nanotextiles which can introduce a multifunctional approach and smart functionalities. Last but not least, textiles and detection systems for high temperatures, oxygen deficiency, and unidentified chemical and biological substances, represent an area of growing interest for synergetic developments across sectors.

In these areas, what stood out the most is that the number of patents, investments and technological developments have increased since 2015, the forecast showing a further growth in the next five years. Until now, the leading countries have been China, Japan, US, New Zealand, and South Korea, with Europe having led international Research Infrastructures and Test Beds to accelerate new product and service developments within new strategic value chains. Based on this strategic road mapping and technology intelligence exercise, the EU-ALLIANCE consortium aims to strengthen Europe's technological knowledge in the field to improve its position amongst global competition, while ensuring proper international collaboration to access markets and generate new ventures.

ACKNOWLEDGMENTS

The work presented in this abstract is based on the background work by the above listed authors. That has been applied in the field of smart textiles and their potential for defence and dual-use within the framework of the project EU-ALLIANCE, Grant Agreement 101035924.

REFERENCES

https://innovation.orbit.com/#/
https://innovation.orbit.com/#/b/~*ybo6mfhzwubzys5523433zrg4aqatsky6r4b7ucbjonbzcc5xjxgwiqvehpoaaa6l7a7vwdx5nkmy000/technology-landscape/research-fields
https://eda.europa.eu/docs/default-source/eda-factsheets/factsheet_stile
https://eda.europa.eu/news-and-events/news/2020/05/27/eda-project-aims-for-multifunctional-smart-textiles-for-defence

Sensors and functional textiles for dual use

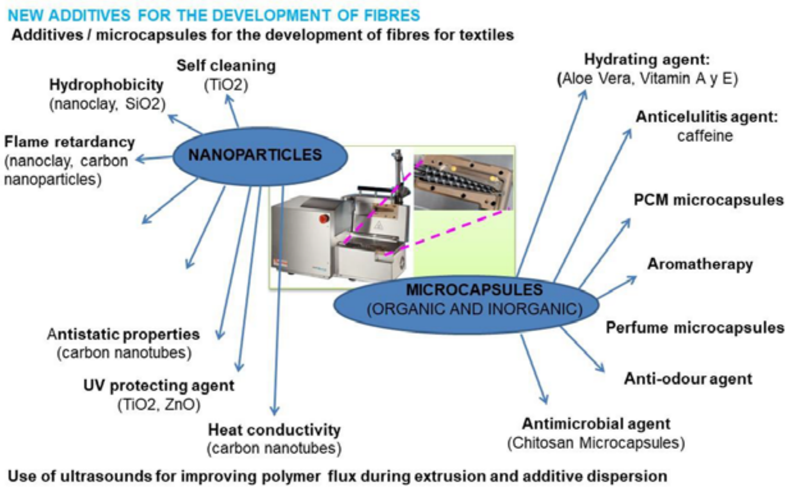
A. Igartua(*), A. Alberdi, M. Blanco, B. Coto, M. Larrañaga
TEKNIKER, C/Iñaki Goenaga, 5, 20600 Eibar, Guipuzcoa Spain
(*)Email: amaya.igartua@tekniker.es

ABSTRACT

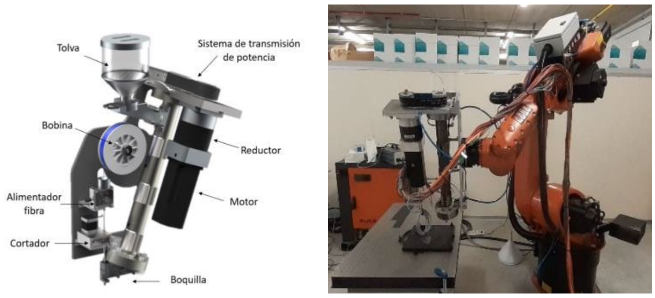
The paper describes different technologies developed by TEKNIKER to enhance the functionality of textiles for dual use applications (civil and defence). Sensors have also been developed to improve the manufacturing process control of these textiles.

RESULTS AND CONCLUSIONS

Functionalisation of polymeric textiles
Two technologies have been used by TEKNIKER to functionalise polymeric textiles: microencapsulation and nanoparticles. Nanoencapsulation is useful when applying to self-cleaning applications (TiO_2), increasing hydrophobicity (eg. using nanoclays, SiO_2), flame retardants (eg. nanoclays, CNPs), electrical conductivity (CNTs, Graphene), UV protection (TiO_2, ZnO) or heat conductivity (eg. CNTs). Nanoparticles have also been used to incorporate hydrating agents (Aloe Vera, Vitamin A & E), thermal control (eg. phase change materials), or to include antimicrobial or biocidal properties (eg. chitosan, or essential oils).



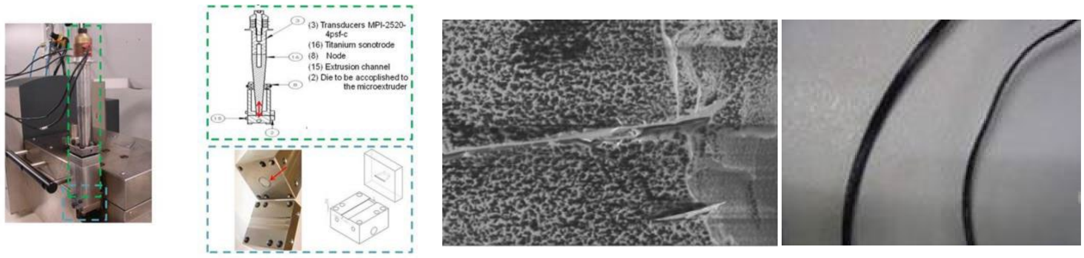
Advanced manufacturing of fibres
Fibres can be incorporated to the composites using additive manufacturing processes. TEKNIKER has developed a head for filament compounding by additive manufacturing, building a robot and a complete cell for additive fibre compounding.



a) b)

Fig. 1.- Advanced manufacturing of fibers and composites : a) Head for additive manufacturing, b) Fiber compounding by additive manufacturing

It is often difficult to disperse the fibres in the composite. In order to facilitate this operation, ultrasonic dispersion has been used, achieving very good results for the preparation of ultrasonic extruded fibres with graphene.



a) b)

Fig. 2. Advanced fibres dispersion a) Ultrasonic dispersion of fibres, b) Ultrasonic extruded fibres with graphene

Roll2Roll deposition and On line monitoring of textiles

Coating can be applied in textiles using Roll2Roll technologies. TEKNIKER has experience depositing solgel organic-inorganic hybrid coatings through this technique. Sensors have been also developed for online textile monitoring quality control during processing. Fig.3 shows the following properties of the process:

a) the In line colorimetry has a medium sensibility, low cost and medium speed,

b) the On line discrimination has a high sensibility, medium cost and low speed, and

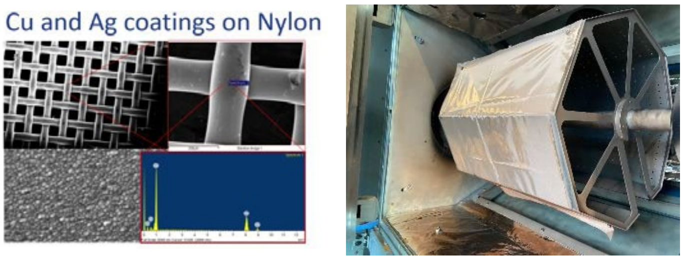
c) the On line non homogeneity detection has a low sensibility (1-3%), low cost and high speed.

a) b) c)

Fig. 3.- Advanced coating production, a) Roll2Roll, b) In line colorimetry, c) On line discrimination and detection of inhomogenities

Textile Metallization

Cu and Ag coatings have been applied in textiles, with antimicrobial properties, electromagnetical shielding properties, electrical conductivity, or thermal control. It has been possible to develop an environmentally friendly metallisation process of natural or synthetic textiles, using Physical Vapour Deposition (PVD) technologies. TEKNIKER has the experience to build adhoc PVD chambers applied by batch or continuous processes.



a) b)

Fig.4.- Textile metalization a) Cu and Ag coatings on nylon, b) textile coating inside a PVD chamber.

Flexible electronics for sensors and actuators

Sensors can be embedded in flexible textiles, for specific purposes. For example, the circuit design on flexible substrates (seamless integration on textiles) using Roll2Roll and inkjet circuit printing has been developed, as well as pick & place for hybrid electronics, or dielectric & metallic coating stacks and selective laser scribbing for integrated sensoring (eg. for pressure & deformation gauges).

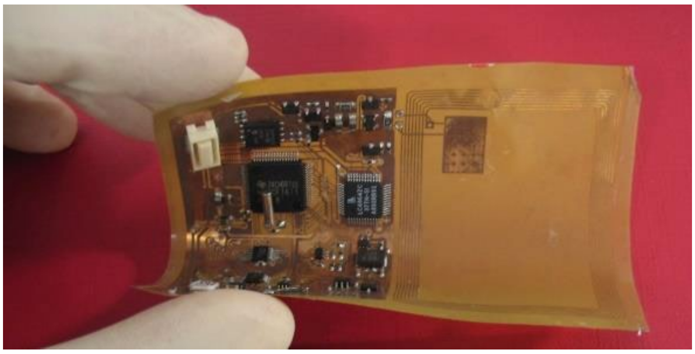


Fig 5.- Example of flexible electronics for sensors and actuators.

ACKNOWLEDGMENTS

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REFERENCES

1. C. Monteserin, M. Blanco, EAranzabe, A. Aranzabe, J.M. Laza, A. Larrañaga Varga, J.L. Vilas, *Effects of graphene oxide and chemically reduced graphene oxide on the curing kinetics of epoxy amine composites,* http://onlinelibrary.wiley.com/doi/10.1002/app.44803/abstract
2. C. Monteserin, M. Blanco, EAranzabe, A. Aranzabe, J.M. Laza, A. Larrañaga Varga, J.L. Vilas, *Effects of graphene oxide and chemically reduced graphene oxide on the dynamic mechanical properties of epoxy amine composites,* http://www.mdpi.com/2073-4360/9/9/449

Providing constant ambient temperature inside the clothing to increase forces' safety and performance during the tactical operation

Rustam Ismailov
Vulpés Electronics GmbH, Germany
Email: ri@vulpes-electronics.eu

There are many examples of the terrible effects experienced by soldiers during military operations conducted during cold weather throughout history. The defence forces must perform strenuous tasks in diverse surroundings: in the desert, in the densely thinned forest or in the cold ice landscape. A too hot or too cold ambient temperature can lead to performance drops and might decrease the responsiveness, which is vital especially during a tactical operation. Furthermore, long-term exposure to cold or hot environment influences performance and metabolism, and might impact the state of one's health.
According to the meta studies from Taylor and Francis [Effects of hot and cold temperature exposure on performance: a meta-analytic review] the temperature drop by 10°C [from 20 to 10°C] and the increase by ~10°C [from 21,1 to ~32,22°C] lead to a decrease of perceptual tasks by ~7.7% and memory tasks by ~18%. Further studies on sportsmen conducting exercises at around 0°C even show a drop of 26% in physical performance and movement velocity.

Smart clothing can support the forces to create a constant ambient temperature inside the apparel, independently of weather conditions. Responsible for the heating and cooling support, the embedded heating and cooling elements are placed on the most sensitive body areas. Thanks to the Vulpés sensor-fusion technology the data for the ambient and the body temperature can be acquired, triggering the autonomous temperature setting even before the wearer notices any cold or warm sensation. The smart clothing knows when and where to activate the heating and cooling support, and can be calibrated to the individual needs of the respective soldier.
The system is battery-driven and can operate from +60 to -50°C. The graphene-based heating elements are extremely robust and withstand heavy-duty applications. Besides, the battery modules are removable and can be charged via an inductive charging module. The clothing items are washable. The electronic design has many safety features to ensure its functionality, and in case of a fall out, the safety of the user.

The internal climate control system can also be attached to other sensors and applications. For instance, the monitoring of vital signs could be linked to the cooling or heating system, providing the proper temperature in the "boost" mode in case a wearer gets a hypothermia or other signs of resilience. The cooling and heating system can also be used during different types of injuries, to treat swelling and inflammation or to increase the tissue production.

Smart clothing for monitoring physical function and performance in the military

Sofia Scataglini[1,2](*), Robby Haelterman[2], Damien Van Tiggelen[1]

[1] Center for Physical Medicine and Rehabilitation, Military Hospital Queen Astrid, Brussels, Belgium

[2] Department of Mathematics, Royal Military Academy, Brussels, Belgium

(*)Email: sofia.scataglini@mil.be

ABSTRACT

Smart clothing - or "intelligent garments" - are becoming indispensable clothes for the soldier of the future, proving to be an intelligent garment for monitoring their performance in a non-intrusive way in different environments [1, 2, 8, 9]. Nowadays smart textiles can potentially be part of a soldier's equipment and be used for monitoring their health status and well-being, stress, environmental safety or empowering human function [9]. Smart clothes are part of the mobile health wearable devices that can be used for monitoring physical and physiological in real-time signal to track an individual's status condition and performance [1, 2, 3, 4, 5, 6, 8, 9] .

In particular, smart clothing based on a body-worn accelerometer can monitor daily activities such as posture and gait by using only one sensor embedded into a smart shirt [8]. Previous studies [6] identified the technological and design issues of smart clothing designing for the military without affecting their performance. Based on this, the collaboration between the Belgian Royal Higher Institute for Defence, the Royal Military Academy, and the Centre for Physical Medicine and Rehabilitation at the Military Hospital Queen Astrid, are aiming to develop mathematical algorithms that could be applied in clinical settings (such as ambulatory or operational settings), to monitor a soldier's status. The concept is to provide a common wearable biomedical sensor system that extends from a preventive to a rehabilitative monitoring program, enabling the Belgian Defence to improve the soldiers' physical performance.

This is possible thanks to a smart shirt based on a body-worn accelerometer for monitoring posture and gait analysis. The possibility of having a smart garment instead of a belt or a patch can preserve the user's comfort without limiting their performance during a task. Previous studies demonstrated the possibility of using this garment for monitoring human balance as an example of destabilisation due to recoil during shooting training [8]. Successively, after understanding this capability for monitoring activities such as posture (and thanks to this project), we identified the ability to monitor spatiotemporal parameters during gait [3]. In fact, other scholars [10] demonstrated that measuring spatiotemporal gait parameters before military training can be considered as a risk assessment evaluation of lower limb overuse injuries.

In conclusion, smart clothing revealed itself to be a potential device for monitoring the soldier in a non-intrusive and ecological approach, which can also provide insights into the rate of recovery and can help prevent illnesses and the wasting of time when regaining active operations. Real-time information from smart technology offers performance information. Insights can be rapidly turned into decisions on how to proactively engage the soldier, their recovery, and administer any support and assistance needed.

ACKNOWLEDGMENTS

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REFERENCES

1. Angelucci, A., Cavicchioli, M., Cintorrino, I.A., Lauricella G., Rossi, C., Strati, S., Aliverti A. *Smart Textiles and Sensorized Garments for Physiological Monitoring: A Review of Available Solutions and Techniques.* Sensors. 2021; 21(3):814.
2. Fernández-Caramés, T.M., Fraga-Lamas P. Towards *The Internet of Smart Clothing: A Review on IoT Wearables and Garments for Creating Intelligent Connected E-Textiles. Electronics,* 2018; 7(12):405.
3. Scataglini, S., Abran, G., Roosens, E., Van Tiggelen, D., Haelterman, R., Verwulgen, S. *Smart clothing for monitoring gait.* In Proceedings of the 6th International Digital Human Modeling Symposium, DHM2020, Skovde, Sweden, 31 August–2 September 2020, Hanson, L., Högberg, D., Brolin, E., Eds., IOS Press: Amsterdam, The Netherlands, 2020.
4. Scataglini, S., Moorhead, A.P., Feletti, F. *A systematic review of smart clothing in sports: Possible application to Extreme sports.* Muscle Ligaments Tendons J. 2020, 10, 333.
5. Scataglini, S., Abran, G., Roosens, E., Van Tiggelen, D., Haelterman, R., & Verwulgen, S. *Evaluation of Golden Gait Approximation Using Smart Clothing.* In: Advances in Intelligent Systems and Computing, 2020, 275–282.
6. Scataglini, S., Truyen E., Perego P., Gallant J., Van Tiggelen D., Andreoni G. *Assessment of Human Balance Due to Recoil Destabilization Using Smart Clothing.* In: Goonetilleke R., Karwowski W. (eds) Advances in Physical Ergonomics and Human Factors. AHFE 2017. Advances in Intelligent Systems and Computing, 2018, vol 602. Springer, Cham.
7. Scataglini, S., Andreoni, G., Gallant, J. Smart *Clothing Design Issues in Military Applications.* In Advances in Human Factors in Wearable Technologies and Game Design. AHFE 2018. Advances in Intelligent Systems and Computing, Ahram, T., Ed., Springer: Cham, Switzerland, 2019, Volume 795.
8. Scataglini S. Ergonomic of gesture. *Effect of body posture and load in human performance,* PhD thesis, Poilitesi, Politecnico di Milano, 11th December 2017.
9. Scataglini, S., Andreoni, G., Gallant, J. A *Review of Smart Clothing in Military.* In: Proceedings of the 2015 workshop on Wearable Systems and Applications (WearSys '15). Association for Computing Machinery, 2015, New York, NY, USA, 53–54.
10. Springer, S., Gottlieb, U., Lozin, M. *Spatiotemporal Gait Parameters as Predictors of Lower-Limb Overuse Injuries in Military Training.* The Scientific World Journal, 2016.

Cotton fabric functionalised with graphene nanoplatelets and its potential as piezoresistive sensors

Luisa M. Arruda[1](*), Inês Boticas[1], João Bessa[1], Fernando Cunha[1], Raul Fangueiro[1,2]

[1] Centre for Textile Science and Technology (2C2T), University of Minho, 4710-057 Guimarães, Portugal,

[2] Department of Mechanical Engineering, University of Minho, 4710-057 Guimarães, Portugal

(*)Email: luisa.arruda@fibrenamics.com

ABSTRACT

Wearables are communication infrastructures that can provide information to monitor areas such as health, well-being and protection. Meeting this demand, if a textile substrate is susceptible to react to a physical or chemical change when subjected to external stimuli, such material, recognised as a smart textile, is potentially usable as a sensor. In this context, a 100% cotton fabric was functionalised with graphene nanoplatelets (GNPs) by the coating knife technique. Its electrical properties and washability, were characterised in order to evaluate its responsive capacity for potentially being integrated into wearable systems as sensors, especially the piezoresistive ones.

INTRODUCTION

Pressure is exerted on objects or other parts of the body in almost every human movement. In order to track these and gain further information, pressure sensors can be integrated into textiles, possibly also obtaining an innovative principle through piezoresistive materials. This kind of properties change their electrical resistance when pressure is applied onto them. In the work under study, a 100% cotton fabric is used, functionalised with three layers of polymeric coating applied by knife coating technique, front and back. The polymeric solution used is based on polyurethane doped with different concentrations of GNPs (2, 3, and 5 %). The GNPs were chosen because they are a carbonbased material that, a priori, are able to change their resistance under mechanical deformation [1].

RESULTS AND CONCLUSIONS

In order to evaluate the electrical resistance, using a Keitley 487 Picoammeter/Voltage Source, a potential difference between –1 to 1 V with a step of 0.1 V was applied at room temperature. Electrical resistance measurements were performed at three different points of the samples, and the resistivity equation was applied: $\rho = R \cdot \frac{A}{L}$, where ρ represents the electrical resistivity (Ω.m), R the electrical resistance (Ω), A the cross-sectional area of the sample (30 mm^2), and L the distance between electrodes (0,02 m). From the resistivity values obtained, the electrical conductivity equation was applied: $\sigma = 1/\rho$, where σ represents the electrical conductivity (S m^{-1}) and ρ the electrical resistivity (Ω.m). The table shows the values of resistance and electrical conductivity obtained for each concentration of GNPs. The resistance range encompassed the order of Ω to kΩ, which, in addition to validating the referred functionalisation, allows the said fabrics to be used in different areas of sensitivity. The samples were subjected to the same electrical resistance test after 10 washing cycles, and the results show that the values become slightly better, which may indicate that after washing, the excess of the polymeric base is eliminated, and the GNPs stay more on the surface, thereby reducing the electrical resistance range.

% GNPs	Electrical resistance (Ω)	Electrical conductivity (S m^{-1})	Electrical resistance after 10 washing cycles (Ω)
2%	2,22E+4	3,00E-2	1,77E+4
3%	4,52E+3	1,47E-1	5,09E+3
5%	9,74E+2	6,84E-1	8,10E+2

Table 1. Electrical properties of cotton fabrics functionalised with GNPs in different %

To measure the piezoresistive properties, two electrodes made of a silver fabric were placed in the sample with 2% of GNPs and connected to a data acquisition board with software in LabVIEW. Thus, it was possible to record the electrical resistance variation over 10 compression cycles, using a universal testing machine with a load target of 100 N, and a compression speed of 30 mm min^{-1} . The Fig 1 indicates that the functionalised sample varies its resistance from an applied force, which confirms its piezoresistive behavior.

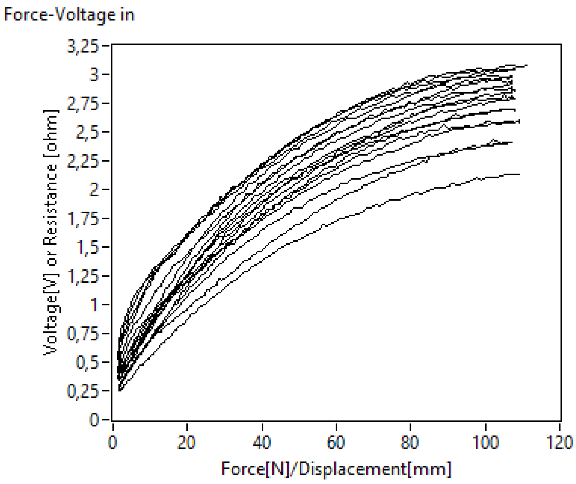

Fig. 1: Relation between electrical resistance and applied force of the fabric sample functionalised with 2% GNPs

In conclusion, the touch as well as the flexibility of the cotton fabric has not been compromised, maintaining its comfort, and the functionalisation with GNPs reached values of conductive materials, with resistance to wash cycles. Furthermore, the piezoresistive property was also achieved, which indicates that they can be integrated into wearable sensors, such as the piezoresistive ones.

ACKNOWLEDGMENTS

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REFERENCES

1. P. Pereira, D. P. Ferreira, J. C. Araújo, A. Ferreira, e R. Fangueiro, *The Potential of Graphene Nanoplatelets in the Development of Smart and Multifunctional Ecocomposites,* Polymers, vol. 12, n. 10, p. 2189, 2020.

Natural fibres and nanoparticles as building blocks for multifunctional fibrous systems

Diana P. Ferreira[1](*), Sofia M. Costa[1], Joana C. Araújo[1] and Raul Fangueiro[1,2]

[1] Centre for Textile Science and Technology (2C2T), University of Minho, Guimarães, Portugal

[2] Department of Mechanical Engineering, University of Minho, Guimarães, Portugal

(*)Email: diana.ferreira@det.uminho.pt

ABSTRACT

One of the most recent and interesting strategies for the development of multifunctional fibrous systems (MFS) is the functionalisation of natural fibres and micro/nanofibres with nanoparticles (NPs). In this work, flax and jute fabrics, as well as PCL microfibres were functionalised with several nanomaterials, like silver (Ag), zinc oxide (ZnO), calcium oxide (CaO), silica (SiO_2) and graphene nanoplatelets (GNPs) in order to introduce several functions, namely antibacterial activity, hydrophobicity, and especially, electrical properties (electrical conductivity and piezoresistive effect).

INTRODUCTION

Over the years, there is an increasing demand for new eco-friendly and multifunctional textiles able to exhibit different properties in the same substrate. These MFS can be applied in a wide range of areas, such as the medical field, electronics, automotive, sports, aerospace and military sectors [1], [2]. Considering the growing of an environmental consciousness, the use of natural fibres is desirable over synthetic ones, because of their biodegradability, biocompatibility, low-weight, high abundance and low-cost [1], [3]. Smart fibrous structures capable of detecting/responding to external stimuli, without hard cables and rigid electronic components, which compromises the user's comfort, have been one of the main focus of different research works [2], [4]. The use of nanomaterials is a very promising approach to introducing several functionalities to the fibres. In fact, the functionalisation of natural fibres with different metal and metal oxide NPs (doped and co-doped) allows for the development of intelligent and MFS with several properties, including electrical conductivity, piezoresistive effect, antimicrobial activity, easy/self-cleaning, decomposition of chemical agents, flame retardancy, UV-protection, EMI shielding and antistatic properties [1], [2], [4]. Micro/nanofibers produced by electrospinning are generating great interest regarding the development of innovative smart fibrous structures, due to their remarkable characteristics, such as high surface-volume ratio, high porosity, lightness and high flexibility. The functionalisation of polymeric nano/microfibers with nanomaterials has been revealed a promising strategy to create flexible systems for monitoring/sensing applications, without adding extra weight to the systems [5].

RESULTS AND CONCLUSIONS

Natural-based fabrics, such as jute and flax, were functionalised with several types of NPs, Ag, ZnO, CaO, SiO_2 and GNPs, in order to develop MFS. GNPs were used to functionalise flax fabrics and PCL electrospun microfibres, which resulted in conductivity values of 0.04 S/m and 0.079 S/m using 2 % of GNPs and gauge factor (GF) values of 1.89 and 3.20 using 0.5 % GNPs, respectively, demonstrating the potential of these samples to be used as piezoresistive sensors (Fig. 1 a-d). NPs of Ag, ZnO, CaO and SiO_2 were successfully synthesised always considering the methodologies' sustainability, allowing the development of systems with electric conductivity, piezoresistive behaviour, antibacterial activity against Gram-positive and Gramnegative bacteria and hydrophobicity (Fig. 1 e-g). Other properties like UV-protection and methylene blue degradation were also obtained.

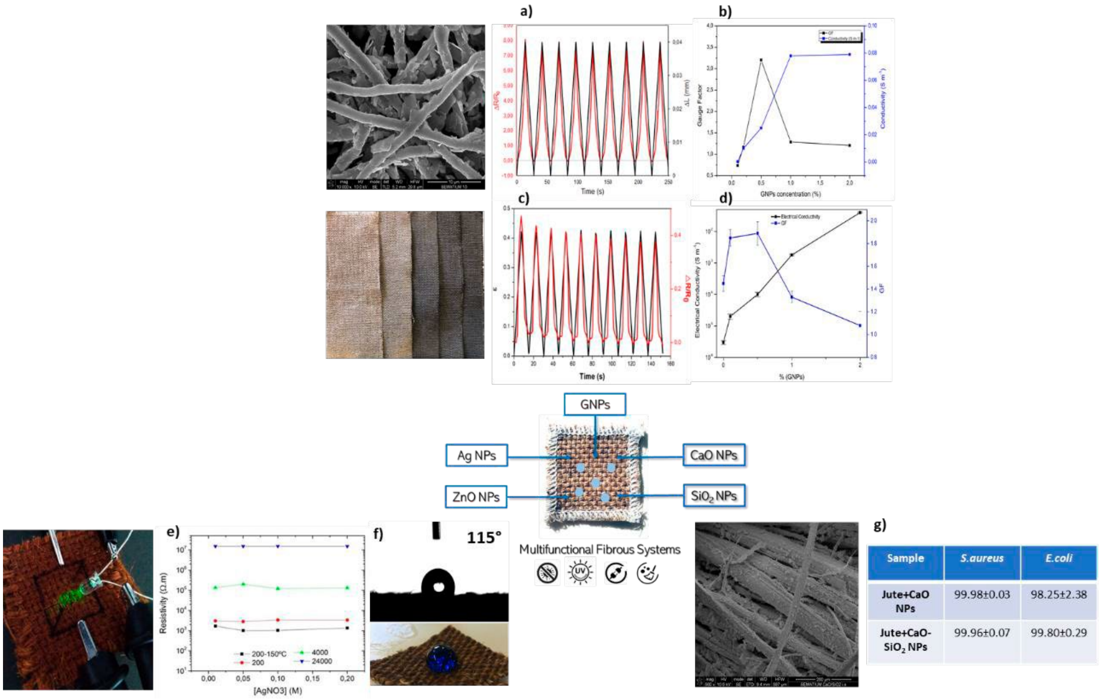

Figure 1. Piezoresistive response of GNPs-PCL membrane (a) GNPs-flax ecomposite (c) and electrical conductivity and GF in relation to the GNPs concentration of GNPs-PCL membrane (b) and GNPs-flax ecomposite (d). Dependence of the resistivity values on $AgNO_3$ concentration for jute fabrics with Ag NPs (e). Water contact angle of flax fabrics with Ag-ZnO NPs (f) and antibacterial activity of jute fabrics with CaO and SiO_2 NPs (g).

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REFERENCES

1. J. C. Araújo, D. P. Ferreira, P. Teixeira, and R. Fangueiro, *In-situ synthesis of CaO and SiO_2 nanoparticles onto jute fabrics: exploring the multifunctionality,* Cellul., vol. 28, no. 2, pp. 1123–1138, 2021.
2. S. M. Costa, D. P. Ferreira, A. Ferreira, F. Vaz, and R. Fangueiro, *Multifunctional Flax Fibres Based on the Combined Effect of Silver and Zinc Oxide (Ag / ZnO) Nanostructures,* pp. 1–21, 2018.
3. D. Ferreira, A. Ferreira, and R. Fangueiro, *Searching for Natural Conductive Fibrous Structures via a Green Sustainable Approach Based on Jute Fibers and Silver Nanoparticles,* Polymers (Basel)., vol. 10, no. 1, p. 63, 2018.
4. P. Pereira, D. P. Ferreira, J. C. Araújo, A. Ferreira, and R. Fangueiro, *The Potential of Graphene Nanoplatelets in the Development of Smart and Multifunctional Ecocomposites,* Polymers , vol. 12, no. 10. 2020.
5. P. Francavilla, D. P. Ferreira, J. C. Araújo, and R. Fangueiro, *Smart Fibrous Structures Produced by Electrospinning Using the Combined Effect of PCL/Graphene Nanoplatelets,* Applied Sciences , vol. 11, no. 3. 2021.

Advanced technical textiles and materials in defence: Is the EU up to the challenge?

José Borges(*), Marco Marsili
Centro de Investigação Desenvolvimento e Inovação da Academia Militar, Academia Militar, Instituto Universitário Militar, Rua Gomes Freire, 1169-203 Lisboa, Portugal
(*)Email: jose.borges@academiamilitar.pt

ABSTRACT

This paper aims to reflect on the challenges of adopting new technologies in Technical Textiles and Materials for defence concerning the current readiness and capacities in the European Union. Identified bottlenecks are the manufacturing readiness, the supply chain capacity and autonomy, and the knowledge and technical skills required.

INTRODUCTION

Defence forces on the various military domains heavily depend on Technical Textiles and Materials (TTM) to ensure their operational readiness. Standard features of TTM must provide several functional performance requirements: physical; environmental; camouflage, concealment and deception; protection against battlefield threats and hazards. Existing technologies already fulfil these requirements and are critical to delivering personal clothing and equipment to the Armed Forces. Some of these requirements are also relevant for other sectors, e.g. security forces, emergency personnel and firefighters, as well a other professions developed in hostile environments, enabling dual-use perspectives of employment for TTM.
The introduction of advanced materials in defence applications primarily attempts to fulfil current functional and operational requirements. Additionally, new applications and functionalities might result from applying the more elaborated features and complexity these materials provide. Some examples are wearable technologies, which will feed data to feed the common operational picture (COP), or dynamic functionalities to provide adaptive camouflage or energy harvesting and storing.
Regardless of the technological sector, disruptive technologies always bring challenges that might stall or even deter its full adoption. This paper aims to revise standard requirements for defence applications, new applications of advanced materials and discuss eventual dysfunctionalities resulting from the adoption of disruptive technologies.

MILITARY REQUIREMENTS FOR DEFENCE TEXTILES AND MATERIALS

Standard requirements for textiles and materials used in combat systems and clothing are grouped according to the operational environment, functionality, or economic considerations [1]. These requirements mostly overlap, sometimes even conflict, due to practical, ergonomic or physical constraints, to ensure a safe and secure operation of personnel, weapons, and other battlefield systems.
The reduction of weight and volume, the increased comfort and durability/stability, the tactical performance (e.g. low noise emissions or antistatic behaviour), or the cleaning and maintenance are among the most relevant physical requirements.
Even when facing normal environmental conditions, the capacity of textiles and materials for protection from water, flame, wind, temperature and light effects, is vital for both the comfort of personnel and the safety of systems. Protection is even more critical in case of extreme environmental conditions directly impacting survivability and operationality.
Regarding camouflage, concealment and deception, the materials need to match the spectrum and blend into the surrounding environments typically observed/detected by enemy forces in a wide range, including the radar, infrared, visual or ultraviolet spectrums.
Protecting personnel and systems against CBRN hazards or battlefield threats, such as bullets, artifacts, or ballistic fragments, is critical for the mission's success.
On top of these technical requirements, there are economic constraints to be considered. For example, given

desired levels of operational capability and compliance with multiple international standards [2], public procurement imposes stringent acquisition processes. These rules will promote competitiveness among suppliers but sometimes compromise quality if rigorous control is not applied. Another consideration to take into account is the environmental impact of these materials along their complete lifecycle, from production to disposal.

TECHNOLOGY CONUNDRUMS

Advances in TTM and manufacturing processes will certainly impact defence and national security over the coming decades. Emergent products and technologies, such as nano-, meta-, auxetic-, or multifunctional-materials, or materials for energy storage and generation, have the potential to enable sound innovation. While allowing to fulfil standard requirements, these products and related technologies will undoubtedly promote innovation in defence applications [3].

Disruptive developments resulting from governmental or industry-driven research and technology (R&T) efforts commonly face several paradoxical conundrums. A significant issue resides in concealing the technology readiness level (TRL) of given technologies and applications with the required industry's manufacturing readiness level (MRL) to ensure short-term sustainability. When the MRL for a given sector is low, the adoption of disruptive technologies with equally low TRL takes longer, is costly, and usually requires substantial public financing.

The defence industrial base is quite asymmetric for the European Union (EU) Member States (MS). Some MS procure defence products outside their borders, while other MS procure internally, strongly investing in R&T and promoting a highly specialised industrial base.

Another issue concerns the supply chains for raw and processed materials to be integrated into the TTM. The scale-up of production for these materials to be integrated into TTM is undoubtedly significant if tied to low MRL. Additionally, the centre of gravity of supply chains lies outside the EU borders, favouring the Asia-Pacific axis. The lack of capacity and autonomy in supply chains might hinder sustainable development in defence technologies. A thoughtful risk assessment is needed while integrating such materials into new defence products to avoid sovereignty issues within the EU MS.

Although R&T is recognisable and significant within the EU, the gap of expertise and technical skills concerning the new technologies in TTM is noticeable. The mindset within academia, R&T centres and industry need to align with this sector's potentialities and clearly understand the added values and benefits.

The new EU funding programmes for research and innovation starting in 2021, namely the European Defence Fund, the Horizon Europe or the EU Space programme, are critical to drive economic growth and create more and better jobs. This seven-year cycle will provide the right setting to explore, develop, and integrate new concepts, technology and capabilities to maintain the EU technology superiority.

REFERENCES

1. R. Scott. *Textiles in Defence.* In: A. Horrocks and S. Anand, Handbook of technical textiles. Woodhead Publishing Ltd., Cambridge, 2000
2. STANREC 4833. *Sizing and fitting of military combat clothing, individual equipment and protection.* NATO Standardization Office, Bruxelles, 2020
3. M. Marsili. *Epidermal Systems and Virtual Reality: Emerging Disruptive Technology for Military Applications.* Key Engineering Materials, 2021, Vol. 893, pp 93-101

Innovative sensor yarns to detect local impact into para-aramid fabric

Quentin WATEL, Anais ROUQUETTE, Cedric COCHRANE, François BOUSSU(*)
ENSAIT-GEMTEX, Univ Lille, 2 Allee Louise et Victor CHAMPIER, 59056 Roubaix, Cedex 01, Hauts-de-France, France
(*)Email: francois.boussu@ensait.fr

ABSTRACT

A sensor yarn has been developed to monitor dynamic strain based on the same raw material as adjacent and close yarns inside the woven structure. The mechanical and electro-mechanical behaviours were characterized in a quasi-static regime and made it possible to access the gauge factor of the sensor yarn. An impact test corresponding to a dynamic regime has been performed and has proven the ability of the sensor yarn to detect the transmitted dynamic wave of elongation to the fabric.

INTRODUCTION

Many studies have focused on the description of woven fabric behaviour when subjected to ballistic impact and have highlighted the parameters that can influence the impact performances of a fabric [1]. During this dynamic event, two damaged zones can be distinguished corresponding respectively to the primary threads which are directly in contact with the projectile, and the secondary threads which are linked to primary yarns without being in direct contact with the projectile [2]. Many parameters influence the ability of a fabric to stop a ballistic impact [3]. The woven pattern [4], the impact velocity [5], the angle between the projectile and the fabric surface [6], and the shape of the projectile [7] are some of these main parameters.
An in-situ measurement could be a solution to filling information gaps about the dynamic behaviour of impacted woven fabrics. These measurements must be performed by a sensor yarn to disturb the local behaviour of the woven structure as little as possible. The main objective of the present work is to develop a sensor yarn with the same properties as a thread used in a ballistic structure, so that the dynamic strain can be detected during an impact.

RESULTS AND CONCLUSIONS

A para-aramid yarn (Twaron©) of linear density 930 dTex has been chosen as the structural yarn due to its use in existing ballistic protection solutions. A batch of 11 sensors was produced for electromechanical testing. A test is considered as failed if the sensor slips from the clamp or if it breaks too far from the sensitive coating during the uniaxial tensile test. Only five sensors were able to obtain useful electromechanical data.

	Strain at break (%)	ΔR/R0 (%) at break	Minimum strain (%)	Gauge factor k
Average	5.35	11.27	0.78	3.31
Standard dev.	0.07	2.38	0.08	0.34
CV%	1.35	21.13	10.17	10.37

Table 1 Statistical results on electromechanical behaviour of sensor yarns

Table 1 presents statistical results on electromechanical behaviour of sensor yarns. The gauge factor k was calculated by linear regression. The sensor yarns in this batch have an average gauge factor k of 3.31 ± 0.34 and represent the coefficient of proportionality between electrical resistance and deformation. The higher the gauge factor k is, the more sensitive the sensor is.

Dynamic characterization

To perform an impact test, a drop tower bench equipped with a normalized knife has been used. A total mass of 1.5 kg with the knife falls from a height of 30 cm and strikes the tested woven fabric at a speed of 1 $m.s^{-1}$ measured by two magnetic sensors. The tested fabric has been extracted from a 3D warp interlock fabric with 5 layers (O-L

3 4-2 -Twill 5 Weft effect-) and made with para-aramid yarns. A sensor yarn has been manually inserted in the weft direction in the last layer of the 3D warp interlock fabric. The 3D fabric coupon equipped with the sensor yarn has been located under 6 plies of 3D fabric in order to avoid any perforation. Thus, the last layer of 3D fabric equipped with the sensor yarn can be suddenly deformed. The electrical resistance of the sensor has been measured using the setup described above. The data frequency acquisition has been set up at 1 kHz.

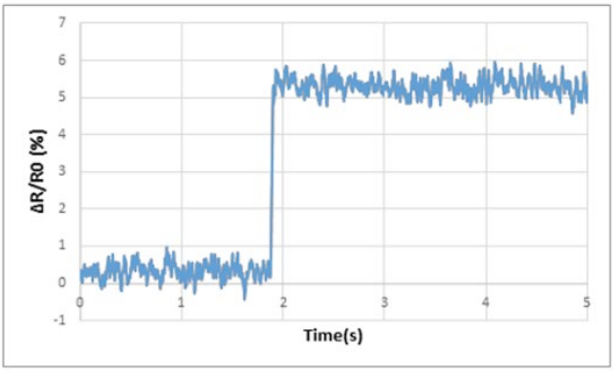

Fig. 1: Variation of the electrical resistance of a sensor impacted on its conductive coating (on left). In the orange circle, the location of the impact (on right).

Figure 1 shows the variations of electrical resistance and the impact location of a sensor inserted into 3D fabrics. Before the impact of the knife, the sensor has a stable variation of electrical resistance near 0%. When the sensor yarn is impacted directly, the variation of electrical resistance passes from 0% to around 5%. As the conductive coating of the sensor yarn is deformed, the electrical resistance stays stable after the impact.

The main goal of the present work was to develop a sensor yarn for in situ and local measurements during an impact. The sensor yarn is designed to have mechanical properties closed to a thread used into a ballistic structure and to sense the dynamic strain. The static gauge factor (k) of the sensor yarn has been determined at 3.31 ± 0.34. A test with a low impact speed (1 $m.s^{-1}$) has been set up to test the sensor yarn into impacted 3D fabric.

Concerning the dynamic test, the impact speed can increase to check the ability of the developed sensor yarn to sense the stress generated by a ballistic impact.

REFERENCES

1. Tabiei A, Nilakantan G. *Ballistic impact of dry woven fabric composites: A review*. Appl Mech Rev 2008. doi:10.1115/1.2821711.
2. Naik NK, Shrirao P. *Composite structures under ballistic impact*. Compos Struct 2004. doi:10.1016/j.compstruct.2004.05.006.
3. Cheeseman BA, Bogetti TA. *Ballistic impact into fabric and compliant composite laminates*. Compos Struct 2003. doi:10.1016/S0263-8223(03)00029-1.
4. Cunniff PM. *An Analysis of the System Effects in Woven Fabrics under Ballistic Impact*. Text Res J 1992. doi:10.1177/004051759206200902.
5. Shim VPW, Tan VBC, Tay TE. *Modelling deformation and damage characteristics of woven fabric under small projectile impact*. Int J Impact Eng 1995. doi:10.1016/0734-743X(94)00063-3.
6. Mascianica FS. Ballistic Testing Methodology, 1980. doi:10.1016/b978-0-444-41928-6.50008-9.
7. Tan VBC, Lim CT, Cheong CH. *Perforation of high-strength fabric by projectiles of different geometry*. Int J Impact Eng 2003. doi:10.1016/S0734-743X(02)00055-6.

EXTRATEX and innovative solutions

Shahin Sayyareh
European Risk and Resilience Institute (EU-VRi)
Email: ssayyareh@risk-technologies.com

ABSTRACT

The European Risk and Resilience Institute (EU-VRi) [1] is the European organization which provides the highest quality of professional service, consulting, information and education needed in the broad area of modern integrated risk management and management of emerging risks. EU-VRi services cover a broad range of industrial sections such as textile, plastic, transport, logistics, oil and gas, e-health, the biomedical industry, corporate social responsibility, environmental and business risk management. With a successful and reliable profile in the mentioned areas, EU-VRi has been a key partner in the European project EXTRATEX. EXTRATEX brings together clusters and SMEs in different industrial sectors, most specifically, textile, plastic, transports and sustainable materials, with a high potentiality of collaboration in technological innovation and technology transfer.

INTRODUCTION

As the demand of risk assessment and resilience tools increases in modern technologies, EU-VRi addresses the industries and research projects on the road to a risk-free, innovative and sustainable future. Some of the main activities of the institute are summarized in Figure 1.

EU-VRi has been recently engaged in the European project EXTRATEX [2], responsible for disseminating the project and publicising its progress and results. The EXTRATEX project will enhance innovation capacities, business models, knowledge and skill levels to determine future business opportunities and increased capacities for European industries. The project consortium, presented in Table 1, consists of a multinational team of scientists from 6 European clusters who have been working towards these goals for nearly 16 months. In general, the objectives of this project are:

1. Creation of a knowledge base
The knowledge base will revise practices and strategies previously implemented in order to put the basis for creating intersectional cooperation and building synergies.
2. Enhancement of skills
Focusing on designing and delivering added-value support services identified by the consortium.
3. Road-map and strategic collaboration: ClusterXchange Pilot phase and fine-tuning of strategic cooperation
The closer cooperation between cluster organizations and a strong impulse to the collaboration, networking and learning for cluster organizations will be ensured by several networking activities and ClusterXchange implementation.
4. Marketing Plan and awareness raising
The previous phases will materialise a marketing plan, also sustained by the awareness raising actions.

RESULTS AND CONCLUSIONS

Only by developing advanced strategies in cross-sector domains and implementing them through comprehensive action plans, the European industry can maintain its global market share and current position. The EXTRATEX project, with its technological services and event programmes, can address the enterprises and clusters towards innovation and optimum use of new technologies. Moreover, IFAST 2021 is considered a great opportunity for the EXTRATEX cluster consortium in order to reach other clusters and SMEs in similar industrial sections and exchange knowledge and technology among them.

Company	Country	Main activity
Next Technology Tecnotessile	Italy	Textile
FOMENTEX	Spain	Textile
Cluster of Technical Textile (CLUTEX)	Czech Republic	Textile
Association of metal companies of Madrid (AECIM)	Spain	Metal
SLOVAK PLASTIC CLUSTER (SPKLASTER)	Slovakia	Plastics
European Risk and Resilience Institute (EU-VRi)	Germany	Risk & Resilience

Table 1 EXTRATEX cluster consortium

Fig. 1 EU-VRi main activities

ACKNOWLEDGMENTS

Alongside the previously discussed actions, the ClusterXchange exchange Programme within the EXTRATEX encompasses exchange activities in which enterprises, managers and other actors visit industrial excellence actors to make an "on-the-job-experience". As a representative of EXTRATEX consortium, EU-VRi is glad to have this opportunity to promote its services and to disseminate the objectives of the EXTRATEX project in IFAST 2021.

REFERENCES

1. https://www.eu-vri.eu/home.aspx
2. https://extratex.eu-vri.eu/home.aspx

Numerical simulation of thermal signature behaviour of the STILE concept

Paulo Teixeira Gonçalves [1](*), Cláudio Monteiro dos Santos [1], José María García Gonzalo [2]

[1] Institute of Science and Innovation in Mechanical and Industrial Engineering (INEGI). Rua Dr. Roberto Frias, 4200-465 Porto, Portugal

[2] Asociación de Investigación de la Industria Textil (AITEX).

(*)Email: prgoncalves@inegi.up.pt

ABSTRACT

Thermal signature is a desired functionality for combat garment in defence applications. Smart textiles have the capability to improve the thermal signature of the human body for camouflaging applications by either active or passive systems. In this work, a finite element model to simulate the thermal signature of the garment was proposed and validated by comparison with experimental results. The garment layers were modelled independently similarly to the body skin, considering its thermal conductivity, specific heat, surface emissivity and body metabolic heat rates. The results show that the proposed model was able to reproduce the temperature profiles under similar ambient conditions. The main parameters affecting the thermal signature are the surface emissivity and the insulation resistance of the clothing.

INTRODUCTION

Smart Textiles are a new generation of materials and systems with interesting multifunctional properties (e.g. camouflage, sensor monitoring, moisture management etc.). Thermal signature is an important functionality in a military garment. The basic philosophy is based upon the assumption that if the enemy cannot detect a target, then that target is effectively protected, and casualties can be avoided. The science of object and people concealment is based on the imitation of their physical surroundings [3].

Effective camouflage must break up the human's characteristic outline and minimise the contrast between them and the environment in terms of colour, texture, shadow, electronic signature, and thermal signature. The thermal IR signature of a dressed soldier can only be changed through appropriate design of the thermal emissivity of both the clothing's surface and its geometric structure for any given environmental condition and personal physical activity level [2].

Many works have been carried in textile design with fibres and pigments to reduce the emissivity because increasing garment isolation also increases body temperature, resulting in an uncomfortable solution for the soldier (Scott 2005) [3].

In this work, a finite element model of the human body with the combat garment was developed to simulate the heat transfer response under different ambient conditions and obtain its thermal signature.

RESULTS AND CONCLUSIONS

The thermal signature analysis was carried out solving the temperature distribution in a typical configuration as shown in Figure 1. In this configuration, the human body wears the combat outfit and is surrounded by ambient air with a known temperature. The ambient air provides free convection heat transfer from the garment surface and the surroundings' radiation heat exchange. The surroundings are modelled with a random temperature distribution to account for a more realistic scenario for the thermal signature. The skin is modelled using the properties provided by the ISO standard 13506:2008 for thermal protection. [1]

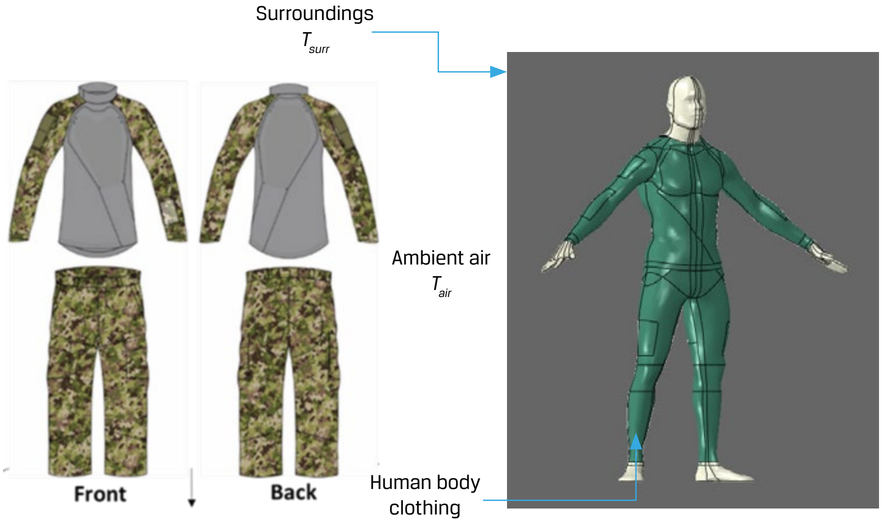

Fig. 1. Body and garment model.

The garment was modelled considering each fabric layer independently. Also, the local thickness, the heat conductivity, the surface emissivity and metabolic heat rate have been taken into account. The overall thickness of the combat garment is 0.5 mm for the underwear, and 1mm for the combat wear in the extremities' areas. The chest area has a complex lay-up which a total thickness of 12.5mm.

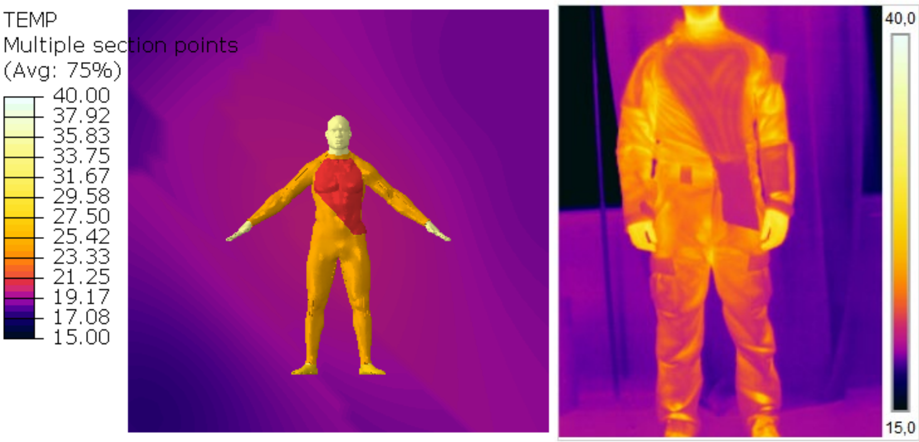

Fig. 2. (a) Numerical thermal signature (b) Experimental thermal signature. At 20ºC ambient condition.

Fig. 2 shows the thermal signature obtained by the simulation model and by the experimental test. The numerically obtained temperature field is uniform because the simulated geometry is free of wrinkles and folds. As can be seen, the surroundings temperature is similar in both conditions. The garment chest area has a lower temperature of 21.5 ºC, compared to the extremities that have 24.5 ºC approximately. The same tendency is observed in the experimental measurements. This difference is due to the fact that the chest garment lay-up has a higher thermal resistance than the extremities.

Additionally, Fig. 3 shows the body thermal signature of changing the garment surface emissivity from 0.98 (that is the current value), to 0.5. The results show how reducing surface emissivity helps improve the thermal signature for disguising purposes, as it tends to be more similar to the surroundings.

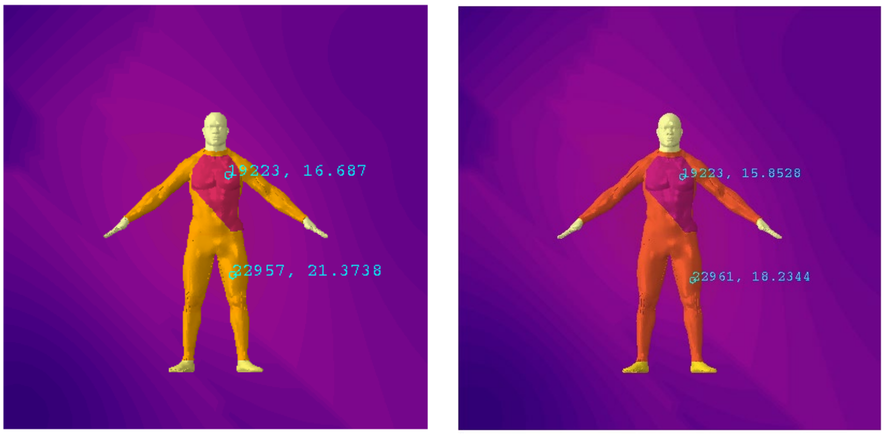

Fig. 3. (a) thermal signature with emissivity=0.98 (b) thermal signature with emissivity=0.50. Results at 15 ºC ambient condition.

REFERENCES

1. *Protective clothing against heat and flame -- Test method for complete garments -- Prediction of burn injury using an instrumented manikin,* Iso (2008)
2. Rubežiene, V., I. Padleckiene, S. Varnaite-Žuravliova and J. Baltušnikaite. *Reduction of thermal signature using fabrics with conductive additives,* Medziagotyra 19(4): 409-414, 2013
3. Scott, R. A., *Textiles for protection, CRC Press,* 2005.

Hybrid and intelligent textile structures for composites structural health monitoring

M. Martins[1](*), J. Guedes[1], D. Esteves[2], K. Rodrigues[2], M. Midão[2], N. Durães[2], S.Silva[2], C. Oliveira[3], L. Rodrigues[3], F. Rodrigues[3], F. Oliveira[3], J Monteiro[5], A. Silva[6], G. Silva[6], S. Oliveira[6],

[1] INEGI : Instituto de Ciência e Inovação em Engenharia Mecânica e Engenharia Industrial

[2] CENTI : Centro de Nanotecnologia e Materiais Técnicos, Funcionais e Inteligentes

[3] CITEVE: Centro Tecnológico das Indústrias Têxtil e do Vestuário de Portugal

[4] INEGI : Instituto de Ciência e Inovação em Engenharia Mecânica e Engenharia Industrial

[5] Simoldes Plásticos

[6] TMG : Tecidos para Vestuário e Decoração, S.A

(*)Email: mmartins@inegi.up.pt

ABSTRACT

Increased environmental concerns on vehicle exhaust emissions are leading to a change in the materials used in the transport sector. Materials with higher strength/stiffness-to-weight ratios such as carbon fibre reinforced polymers, have definitely gained relevance. One of the research focus has been on the development of multi-functional composites, on to which the typical high mechanical properties linked with low weights are added additional functionalities, such as smart ones. This work presents the achievements of TexBoost project (PPS3), aiming at the integral development of new Technical and Intelligent Structures directed to the use in composites in the automotive sector.

INTRODUCTION

Textile composites, which combine a polymer matrix with a textile reinforcement, can be considered an attractive alternative to unidirectional composites, since they allow easier and automated manufacturing of complex component shapes. The intrinsic properties of textile structures, such as flexibility or good compromise between strength and lightness, the variety of possible structures combining different materials, fibres and yarns with maturity and know-how in processing technologies, make the textile solutions applicable in a wide range of domains.

This activity had the main purpose of developing new hybrid and intelligent textile structures for the reinforcement of thermoset composites with sensing capability, which act as a reinforcement and also allow for the monitoring of the performance of structural parts, aiming to predict eventual failures and the need for part replacement (preventive maintenance of components).

RESULTS AND CONCLUSIONS

Piezoresistive and piezoelectric functional fibres with side-by-side and sheath-core geometries, respectively were produced (see Fig.1). Based on these fibres, piezoresistive and piezoelectric yarns were obtained, each one with 36 filaments. Piezoresistive yarns were based on filaments with 30% PP + 70% of a carbon black based conductive elastomeric compound, whilst piezoelectric ones were based on filaments with 75% Polyvinylidene fluoride + 25% of a carbon black based conductive polymeric compound.

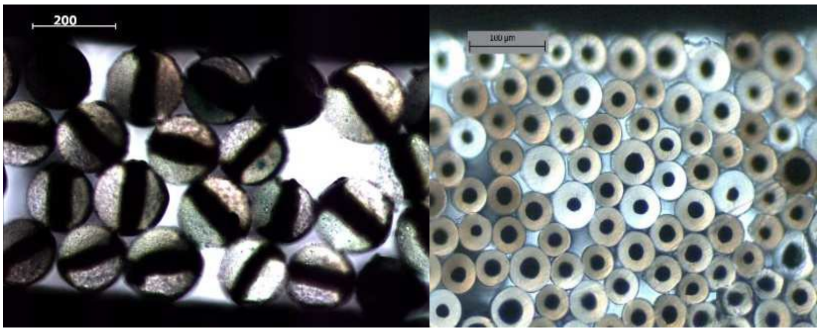

Fig.1: Tri-component side-by-side geometry of the piezoresistive fibres (left) and Bi-component sheath-core geometry of the piezoelectric fibres (right).

The electrical resistance of piezoresistive fibres was measured under cyclic strain, where a maximum strain variation of 10% was imposed, and the electrical resistance was measured along the time with a frequency of 0.04 Hz. The filaments show a clear electrical variation under cyclic strain. A higher amplitude of response for a higher draw ratio is observed. The piezoresistive fibres can be integrated on textile structures, acting as fully integrated piezoresistive sensors in composites structures.

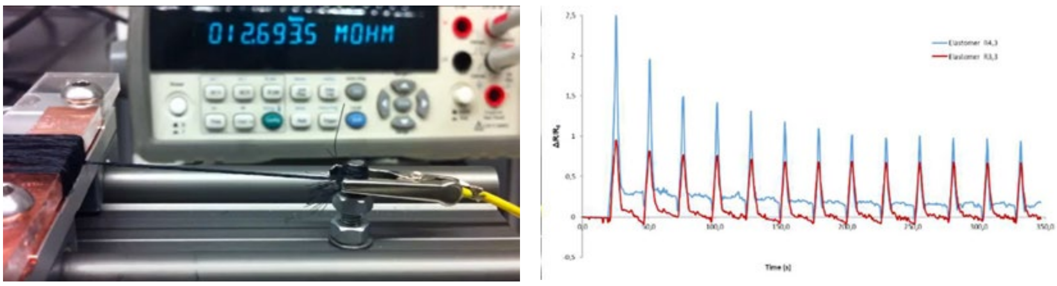

Fig. 2: Electrical resistance measurements under cyclic strain

The piezoelectric fibres were polarised and characterised concerning its performance through output voltage, in which the bi-component PVDF fibres act as an outer electrode. The results of the press and release tests of the fibres, with insulated copper wire as an outer electrode, show that the fibres were able to generate a proportional output voltage for the different applied forces. This behaviour can be used to detect impacts or damages in composite structures under vibration at higher frequencies.

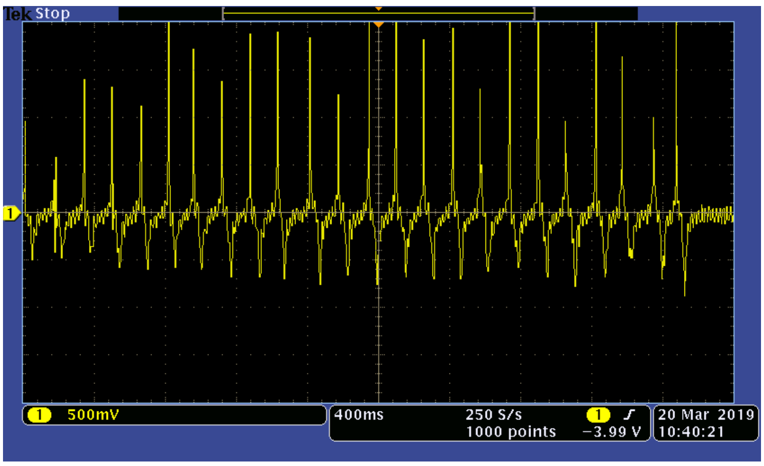

Fig. 3: Output performance of F-Piezo component with bi-component yarn twisted with 100 µm copper wire.

The piezoresistive fibres were the first ones integrated in the carbon fibre textile reinforcement structure, with the yarns integrated at warp and weft directions (spaced by 3.5 cm), being fully compatible with the weaving process used. A basic taffeta textile structure was produced on a Dornier loom.

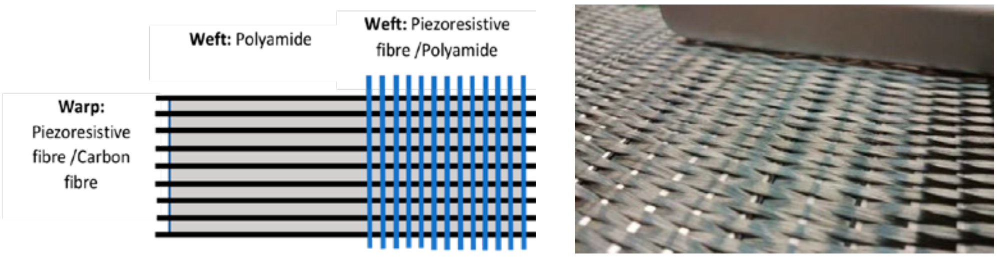

Fig.4: Integration of the piezoresistive fibres in the carbon textile structure

Different approaches were considered for the integration of the piezoelectric yarns in the textile reinforcement structure: (i) the integration of the piezoelectric yarns without an external electrode, taking advantage of the excellent electrical properties of carbon fibre to act as the external electrode and (ii) the integration of the piezoelectric yarns already twisted with the copper wire, improving the piezoelectric performance.

Composite sheets were manufactured by a hand lay-up followed by an autoclave curing cycle, using the developed carbon-based textile structures as reinforcement and a low viscosity epoxy resin as matrix.

Fig. 5: Details of composite manufacturing stages and obtained composite

In order to characterise the sensing capabilities of the developed hybrid composites, electrical interconnections with the sensing piezoresistive yarns integrated in the textile reinforcement structure were developed. Afterwards, the materials were characterised regarding compression detection. For this, the sensing yarns embedded in the composite structure were monitored during compression events, testing both single and repeated mechanical compression.

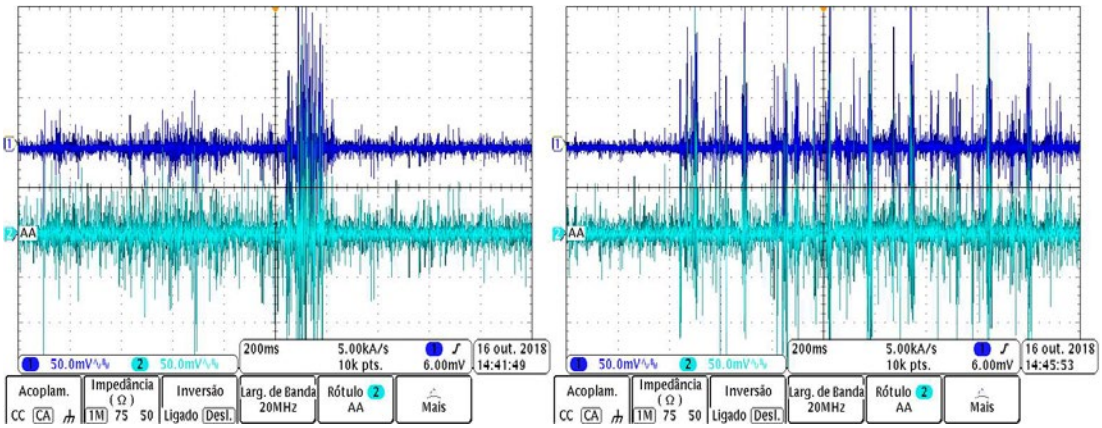

Fig.6: Composite response during mechanical compression (left) and repeated compression cycles (right)

The produced hybrid composite is able to detect both single and multiple compression cycles. The detected high signal noise may result from the non-insulation of the side-by-side piezoresistive fibres. Thus, it is possible that the high conductivity of the carbon fibres applied in the textile reinforcement structure may interfere with the electrical performance of the integrated piezoresistive yarns.
The current developments show the high potential of functional fibres to be applied in textile reinforcements for composites, enabling sensing capabilities to the final structure without compromising the composite's mechanical performance. It was demonstrated that the integration of piezoresistive fibres result in functional composites capable of detecting mechanical events, more precisely mechanical compression. Additionally, the compatibility of the sensing fibres with conventional weaving and composite production processes was proven.

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Antimicrobial/virucidal nanocomposite coatings

Balagna C.[1](*), Luceri A. [1], Perero S.[1], Francese R. [2] , Lembo D. [2] , Ferraris M.[1]

[1] Dept. of Applied Science and Technology, Politecnico di Torino, Corso Duca Degli Abruzzi, 24, 10129, Torino, Italy

[2] Dept. of Clinical and Biological Sciences, Laboratory of Molecular Virology and Antiviral Research, University of Turin, San Luigi Gonzaga Hospital, Regione Gonzole 10, 10043 Orbassano, TO, Italy

(*)Email: cristina.balagna@polito.it

ABSTRACT

An antimicrobial/virucidal nanocomposite coating was deposited by sputtering on several textiles - including cotton - high-performance synthetic fabrics, respiratory masks and other fiber-based materials. The nanocomposite coating is composed of metallic nanoclusters embedded into the silica/ceramic matrix. The layer homogeneously coated all fibers, optimizing the co-sputtering process parameters. A controlled and gradual release of silver ions was verified without dispersing nanoclusters into the environment. The coating conferred all textiles a good antimicrobial and virucidal activity towards several bacteria, fungi and respiratory viruses including severe acute respiratory Coronavirus 2 (SARS-CoV-2).

INTRODUCTION

Air-transmitted pathogens as bacteria, fungi or viruses are the cause of several airborne diseases, from colds or influenza to even more acute respiratory illnesses. The current pandemic of COVID-19, caused by SARS-CoV-2, induced the commissioning of new protocols in order to cope with it. Several studies demonstrated the antimicrobial/virucidal behaviour of silver ions and nanoparticles, thanks to their broad-spectrum activity [1]. From the beginning of the pandemic, numerous silver-based solutions were commercialised to confer antimicrobial/virucidal action to textiles, individual protection system (respiratory masks, coats, gloves, uniforms) and other surfaces. Examples are sprays by Microban® or adhesive membranes and coatings [2, 3]. In this context, our nanocomposite coating is proposed for a dual-use technology aimed for the military and civil sector as it can limit the contagion risk for healthcare staff and patients, service-persons and the remaining population. The patented nanocomposite coating was deposited by co-sputtering [4] on several substrates (biomedical implants, mobile phone, aerospace structures and air filters), and tailoring the process parameters according to the requirements of application. It was successfully deposited on natural and technical textiles [5-7]. The co-sputtering is a green method widely used for several applications, easily transferable to an industrial level and versatile in terms of coating composition and substrate surface. The process can be applied to finished products already on the market by giving them new functionality with a very fast procedure and an estimated cost comparable to other techniques (e.g. plasma spray or impregnation).

RESULTS AND CONCLUSIONS

The antimicrobial/virucidal coating (less than 200 nm) is composed of silver nanoclusters (or other metals) well embedded into a silica or zirconia matrix. It is characterized by a gradual controlled metallic ion release without the dispersion of nanoclusters into the surrounding environment. Silver can be absorbed through human skin in vitro, remaining stored only in the epidermidis. The coating has been shown to be effective against SARS-CoV-2 [8], other respiratory viruses [9] and several bacteria and fungi [5,6]. Moreover, it is able to withstand thermal treatment up to 450°C without changing its properties, useful for the thermal regeneration of textiles, not sensitive to high temperature. The deposition does not alter the original properties of uncoated textiles (e.g. flammability, water repellency, breathability, mechanical and flexibility resistance), as setting the sputtering parameters can match different requirements according to the application. An example of coating deposition on cotton is reported in Fig. 1, comparing uncoated and coated textile in terms of colour, antibacterial, and antiviral effect. A darkening of the surface textile due to the silver nanoclusters occur also with a deposition of very thin layer (ThinCoat, less than 60 nm). It increased for coating of about 300nm (ThickCoat) (Fig. 1a). Regardless, this issue could be overcome using other matrix and metallic nanoclusters. Both the two coatings reported here are able to form a well visible inhibition halo towards *S. aureus.* Lastly, the silver nanoclusters/silica composite coating shows a strong virucidal activity against respiratory syncytial virus (RSV) in a test simulating a close contact between infectious viral aerosol and cotton (Fig.1b). The coated cotton significantly reduces the number of infectious RSV particles, if compared with the uncoated cotton and the control.

In conclusion, the nanocomposite coating can help limit antiviral/antimicrobial biohazards, both in the military, civil and health sector. It can improve the current prevention and safety procedures, conferring an add value to the uniforms and protective clothing such as gowns, masks or gloves. In addition, staff and workers operating in critical conditions such as hospitals, conflict areas or regions affected by natural disasters or pandemics, could benefit from the antimicrobial/virucidal nanocomposite coating.

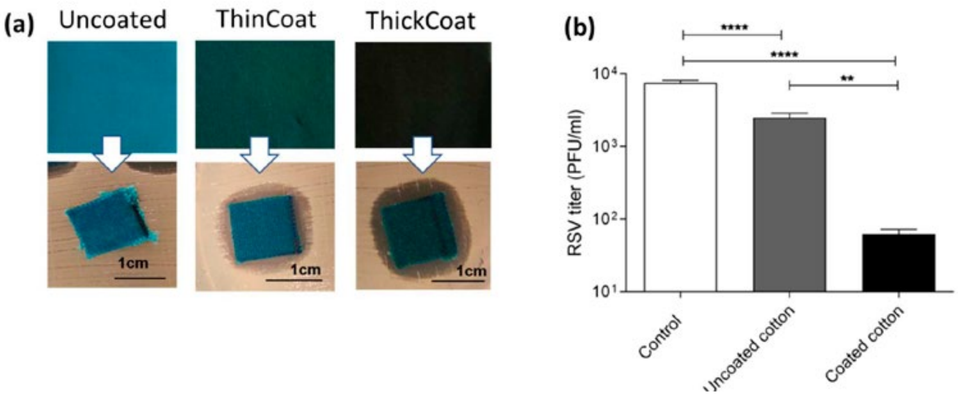

Fig.1: Silver nanocluster/silica composite coating on cotton: (a) comparison of colour of uncoated textile and thin (60 nm) and thick (300 nm) coatings and relative inhibition halo test towards S. aureus; (b) antiviral tests against RSV, comparing coated and uncoated samples with the control referring to the incubation of only viral particles.

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REFERENCES

1. Ciriminna et al. *New Antivirals and Antibacterials Based on Silver Nanoparticles,* Chem. Med. Chem, 2020, 15, 1619–1623
2. https://www.microban.com/it
3. https://www.sergeferrari.com/agivir
4. M. Ferraris, C. Balagna, S. Perero, *Method for the Application of an Antiviral Coating to a Substrate and Relative Coating,* 2019, PCT/IB2018/057639
5. Irfan et al. *Antimicrobial functionalization of cotton fabric with silver nanoclusters/silica composite coating via RF co-sputtering technique,* Cellulose, 2017, 24, 2331–2345
6. Balagna et al. *Characterization of antibacterial silver nanocluster/silica composite coating on high performance Kevlar® textile,* Surface & Coatings Technology, 2017, 321, 438–447
7. Ferraris et al. *Chemical, mechanical and antibacterial properties of silvernanocluster/silica composite coated textiles for safety systems andaerospace applications,* Applied Surface Science,2014, 317, 131–139
8. Balagna et al. *Virucidal effect against coronavirus SARS-CoV-2 of a silver nanocluster/silica composite sputtered coating,* Open Ceramics, 2020, 1, 100006
9. Balagna et al. *Nanostructured composite coating endowed with antiviral activity against human respiratory viruses deposited on fibre-based air filters,* Surface & Coatings Technology, 2021, 409, 126873

Flight Sensing Shirt – a smart shirt for physiological monitoring of fighter pilots

Charlotte Kjellander[1](*), Kaj Gijsbertse[2], Pradeep Panditha[1], Shavini Stuart[1], Erik Frijters[3], Pierre Valk[2], Boris Kingma[2]

[1] TNO, The Netherlands Organization for Applied Scientific Research, the Holst Centre, Eindhoven, The Netherlands

[2] TNO, The Netherlands Organization for Applied Scientific Research, Dep. Human Performance, Unit Defense, Safety & Security, Soesterberg, The Netherlands

[3] Royal Netherlands Airforce, Center for Man in Aviation, Soesterberg, The Netherlands

(*)Email: charlotte.kjellander@tno.nl

ABSTRACT

Unexplained Physiological Events (UPEs) are significant threats to military pilots. Yet, these abnormal physiological events are associated with a range of circumstances from hypoxia to gravity-induced loss of consciousness. With aircraft technology advancements the cognitive burden on military pilots increases. There is a growing demand for systems with the capability to alert pilots to potential UPE episodes. Improvements within sensor technology and integration possibilities within wearable electronics provide a new opportunity in incorporating personalised monitoring systems within extreme environments from increased G-forces to high temperature and pressure changes. Using expertise within hybrid printed electronics, wearable device development and textile selection, we have designed and tested sensing shirt prototypes for continuous assessment of the pilot's physiology and the external environment. These have been tested for initial learnings within practical, real-time applications.

INTRODUCTION

There is a need for sensors that can monitor the physiological status of a pilot and provide real-time feedback. This helps to understand UPEs and to optimise flight-performance and prevent loss of life and loss of aircrafts. It is, however, not easy to introduce reliable sensors into the environment of pilots. Such sensors must be able to record physiological data in adverse conditions, such as accelerations larger than 8G, combined with extreme temperature and pressure changes. Additionally, the sensors must comply with aviation regulations. To meet these needs, our research focuses on the design of smart shirts with integrated sensors for reliable and robust physiological monitoring during flights. Besides the robustness of measured bio-signals, the shirt must be producible in large volumes by industrial processes. To respond to these requirements, we design and fabricate wearable prototypes known as the 'Flight Sensing Shirt'.

To assess challenges faced within operational conditions, judge the integrity and iterate the wearable design concepts, we test the prototypes within two physical simulator platforms: human centrifuge at Center for Man in Aviation, Royal Netherlands Air Force, and TNO's flight simulator DESDEMONA.

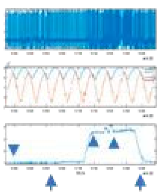
RESULTS AND CONCLUSIONS

The novel dry electrode technology utilised is comprised of ultra-thin medical-grade skin-contact sensors for ECG and bio-impedance monitoring. The electrodes are laminated on stretchable circuitry that is printed on thermoplastic polyurethane (TPU) substrates. The TPU is seamlessly laminated on to fabrics for a slim, and comfortable fit of the garment. Two main integration approaches were investigated: constant or replaceable integration into the undershirt of the pilot. The specific location of the sensors was tested to ensure high sensor signal quality and low disturbances resulting from interaction with other equipment (e.g. safety-belt or G-suit). The requirements for the fabric are stringent, besides the function to support the sensor measurements robustness; safety and comfort aspects, as well as breathability and fire retardancy need consideration and evaluation.

Validation of shirt prototypes in the human centrifuge and flight simulator DESDEMONA allow us to introduce operational conditions and disturbances in a controlled manner. We collected bio-signals for ECG and respiratory status using strict test protocols during increasing G-forces. Analysing the data, we can draw links between the quality of the measured bio-signals and the measurement position, sensor materials, fabrics and design of shirts. The learnings gathered from these tests highlight two main challenges: motion artifact of sensors (skin-electrode contact and measurement robustness), and interconnection of stretchable circuitry to readout electronics.

Additionally, converting physiological data into actionable information can increase flight safety. We investigated the complex relationship within bio measurement data to develop graphical user interfaces. This enabled pilots to obtain insights of their physiological response during flights. The pilot can be informed using warnings when physiological parameters are outside of normal. This has the potential to assist in the decision making process, mitigating or even preventing UPEs.

Introducing robust physiological sensing solutions into the cockpit has the potential to prevent many UPEs from occurring. The Flight Sensing Shirt offers promising new technology to support operators and senior leadership. Preventing UPEs can save lives and increase mission effectiveness. It also can provide insight into physiological parameters during physiology training (e.g. centrifuge, hypobaric chamber). In the next phase, we are aiming to bring the Flight Sensing Shirt to technology readiness level 7 by refining the sensor design for increased robustness, develop scalable process designs and validate Flight Sensing Shirts jointly with a smart alert system.

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Smart garment with vibrotactile feedback for stress prevention

Charlotte Kjellander[1](*), Pauline van Dongen[2], Linda van Peppel[1], Milan Saalmink[1], Maxime Dassen[1], Gert van Heck[1], Jeroen van den Brand[1,3]

[1] Holst Centre, TNO, Eindhoven, the Netherlands

[2] paulinevandongen.nl, Arnhem, the Netherlands

[3] University of Ghent/CMST group, Belgium

(*)Email: charlotte.kjellander@tno.nl

ABSTRACT

Stress, burnout and other societal challenges are serious threats to our well-being and productivity. Organisations and industries are affected globally. Curing and prevention demand personalised solutions that are unpretentiously implemented in everyday context. Clothing with invisible integrated on-body sensing and actuating devices, and direct connectivity between the human body and digital networks can be enabled by using stretchable and thin printed electronics. Here we show smart clothing concepts for stress prevention; seamlessly integrated ultra-thin inlays of stress sensors and haptic motors in comfortable clothing produced by large volume manufacturing processes. Through haptic touch sensations, body awareness is stimulated by the garment, which supports regulation of stress and emotions. This smart garment can be tailored to specific needs, building on the same principle: monitoring of stress levels with closed loop activation of vibrotactile relaxation.

INTRODUCTION

Burnouts and chronic stress caused by high workloads are a rising social and economic dilemma. Today more than 84 % of all Americans experience prolonged stress according to the American Physiological Association [1]. Preventive therapy using relaxation techniques, as stress management, body awareness-and breathing exercises have proven to improve the recovery of heart diseases [2]. Although controlled breathing is known to influence neurophysiological processes and enhance therapeutic results, the physio-behavioural processes, are still to be unraveled [3,4]. In everyday life, breathing exercises can offer a solution to stress reduction, but it can be challenging for individuals to make such exercises a part of their daily routine. Therefore, we designed a smart shirt that creates a moment of relaxation by guiding the wearer through breathing exercises using vibrotactile feedback.

Here, the MYSA concept (Fig. 1) senses stress by increased respiration frequency. An increase initiates the breathing guidance of the seamlessly integrated vibration motors placed at the lower back and spine of the shirt. These motors guide the wearer towards a slower and deeper breathing pattern. By enhancing body awareness, stress can be prevented and healing stimulated.

Figure 1. MYSA: Smart garment with vibrotactile feedback for stress prevention.

RESULTS AND CONCLUSIONS

The shirt is designed for wearing comfort. We selected a Lyocell fabric, made from natural and sustainable raw materials (cellulose from wood pulp) and known for its silky soft feel and beautiful drape (Fig. 1), to create a 'second skin'. The sleeveless shirt in soft, composed colour offers versatility in wearing, as it can be worn on its own or layered with other garments. Vibration motors are positioned along the spine and at the lower back; they are connected to printed conductive tracks that are seamlessly bonded to the fabric (Fig. 2). The back panel of the garment consists of a second layer that can be tied around the body to increase contact between vibration motors and the body, enhancing the tactile sensation. Breathing exercises are translated into haptic patterns, delivered by the motors.

Figure 2. Vibration motors and printed electronics circuitry seamlessly integrated on the fabrics.

The breathing rate and depth can be continuously monitored by measuring bio impedance using intimate skin-contact electrodes [5] (Fig. 3). Recent developments in dry electrode skin-contact bio sensors and smart skins with intimate and conformable electronics invite large volume production methods of ultra-thin and stretchable printed electronics suitable for integration in smart fashion articles [6,7].

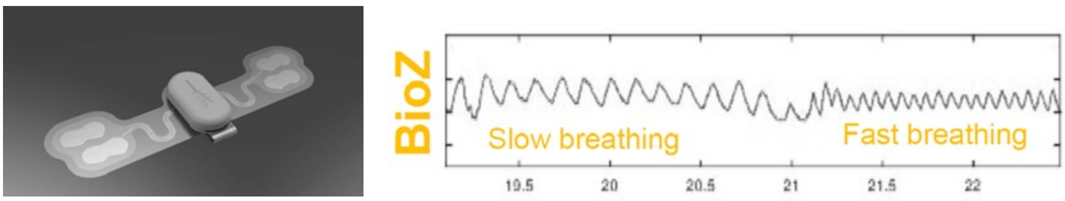

Figure 3. Graphically imaged health patch with skin-contact sensors on the left and right wings (left), and measured bio-impedance signals from the health patch that detect breathing frequency and depth (right).

As part of the validation of the garment, we hand-washed it five times (Fig. 4). After each washing cycle we noted an increase in the average driving power of the vibration motors, and the total change was 4,4 ± 3,3 % which falls within the accuracy of the measurement setup (3-5 %). The performance of the integrated vibration motors remained unchanged after a consecutive use of washing machine gentle programs.

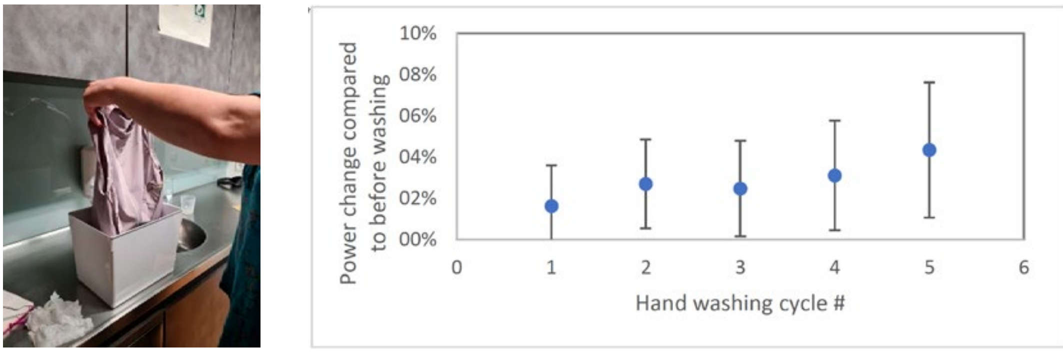

Figure 4. Hand-wash validation of the MYSA shirt.

With a feedback loop between sensor input and haptic output, the selected breathing exercise can be adapted to the actual breathing rate of the wearer to achieve a more personalized and comfortable interaction. Unlike existing mobile apps and wrist-worn wearables that focus on visual and auditory breathing guidance, wearers of MYSA can draw attention to their bodies more easily through the tangible experience the garment offers.
To gain insights of the overall experiential qualities of MYSA, the next step is to perform field tests to validate the effectiveness in reducing stress in the short and long term. With this, we aim to deliver value to people in their daily work environment.

ACKNOWLEDGMENTS

Special thanks to Piet Bouten and Veronique Barthelemy, TNO, for their fundamental understanding of circuitry design and stretchability for printed electronics inlays of smart fabrics. Initial studies on the MYSA concept have been presented at the conferences Eurohaptics 2020 and LOPEC 2021.

REFERENCES

1. https://www.apa.org/news/press/releases/2021/02/adults-stress-pandemic
2. J. van Dixhoorn, A. White. *Relaxation therapy for rehabilitation and prevention in ischaemic heart disease: a systematic review and meta-analysis,* Eur. J. Cardiovasc. Prev. Rehabil., 2005, 12, 193–202, doi:10.1097/01.hjr.0000166451.38593.de
3. V. Perciavalle et al. *The role of deep breathing on stress,* Neurol. Sci., 2017, 38, 451–458, doi:10.1007/s10072-016-2790-8
4. D.J. Noble, S. Hochman. *Hypothesis: Pulmonary Afferent Activity Patterns During Slow, Deep Breathing Contribute to the Neural. Induction of Physiological Relaxation,* Front. Physiol., 2019, 10, 1176, doi:10.3389/fphys.2019.01176
5. H.B . Wang et al. *A robust electrode configuration for bioimpedance measurement of respiration,* J. Healthc. Eng., 2014, 5(3), 313-27, doi:10.1260/2040-2295.5.3.313
6. P. Zalar et al. *Screen-Printed Dry Electrodes: Basic Characterization and Benchmarking,* Adv. Eng. Mater. 2020, 22, 11, doi.org/10.1002/adem.202000714
7. T. Someya, M. Amagai. *Toward a new generation of smart skins,* Nat. Biotechnol., 2019, 37, 382–388, doi.org/10.1038/s41587-019-0079-1

Dynamically Smart Textiles

Nils-Krister Persson[1](*), Edwin Jager[2]

[1] Polymeric E-textiles, Swedish School of Textiles, Smart Textiles, University of Borås, SE-501 90 Borås, Sweden

[2] Div. Sensor and Actuator Systems, Dept. Physics, Chemistry and Biology (IFM), Linköping University SE-581 83 Linköping Sweden

(*)Email: nils-krister.persson@hb.se

ABSTRACT

Textiles have traditionally been regarded as passive materials. Now there is an on-going paradigm shift of enriching textiles with novel functionalities so they become active (i.e. able to exert mechanical force on its surrounding and/or changing shape due to built-in mechanisms). Such behaviour is here denoted actuation.

We will show examples of activities within the Smart Textiles initiative where the Swedish School of Textiles (University of Borås), is involved in. Smart Textiles are the largest resource for research and development of advanced textile materials and textile products in northern Europe.

INTRODUCTION

There are many physicochemical mechanisms that can be employed for obtaining textile actuation. We have mapped the potential for textiles through a study (Fig 1). More details are present in [1, 2]. Exploring the possibilities of "textilifying" (i.e., integrating them in textiles), or even using textile processes for re-realising them, is an ongoing research activity of ours alongside academia, the industry and public sector.

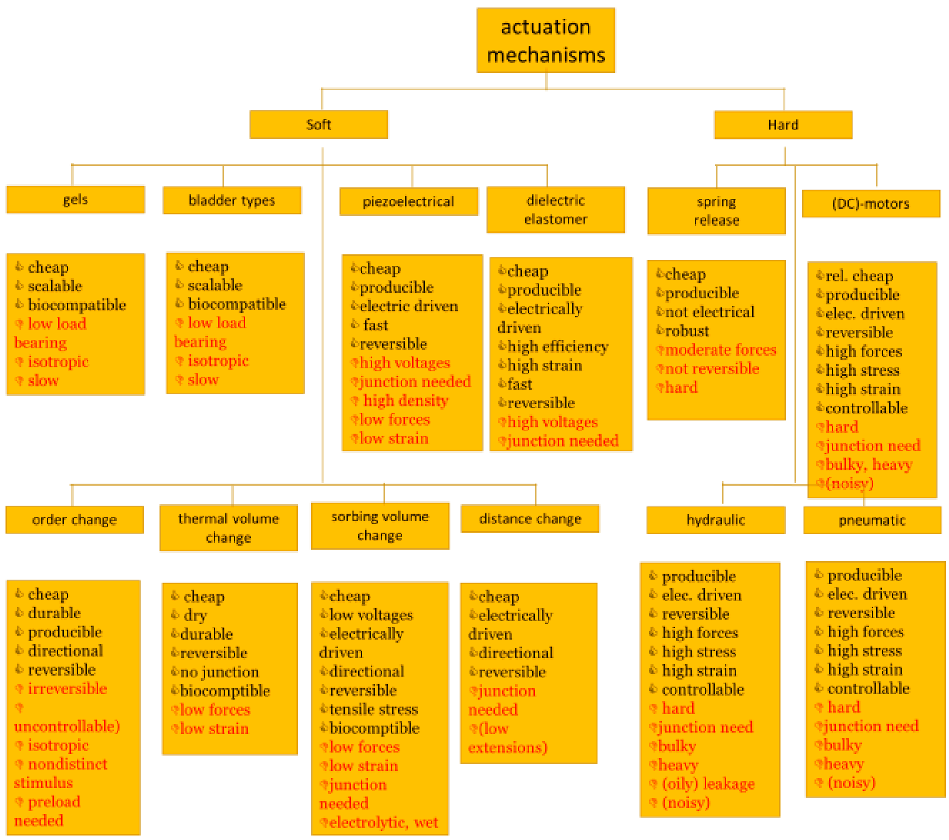

Fig. 1 Actuation mechanisms and their indicative potential or characteristics (black) as well as problematic characteristics (red). It should be noted that positive and negative properties are highly context dependent.

RESULTS AND CONCLUSIONS

We hereby briefly give two examples of exploring these mechanisms in a textile context. These mechanisms are the hard technique of DC-motors, and the soft thermal volume change. Simultaneously, we address two different levels. This means that we are exploring the fact that textiles are hierarchical materials also consisting of fibres, and in turn, building blocks for yarns that are put together in fabrics and out of fabric garments and textile systems are made.

At a fibre level, we have demonstrated thermotropic polymer-based fibres (Fig. 2a). Thermal stimulus creates a shape change. The process is fully reversible. Such fibres could also be further integrated in textile construction for haptic communication. In Fig. 2b, actuation at the garment level is shown.

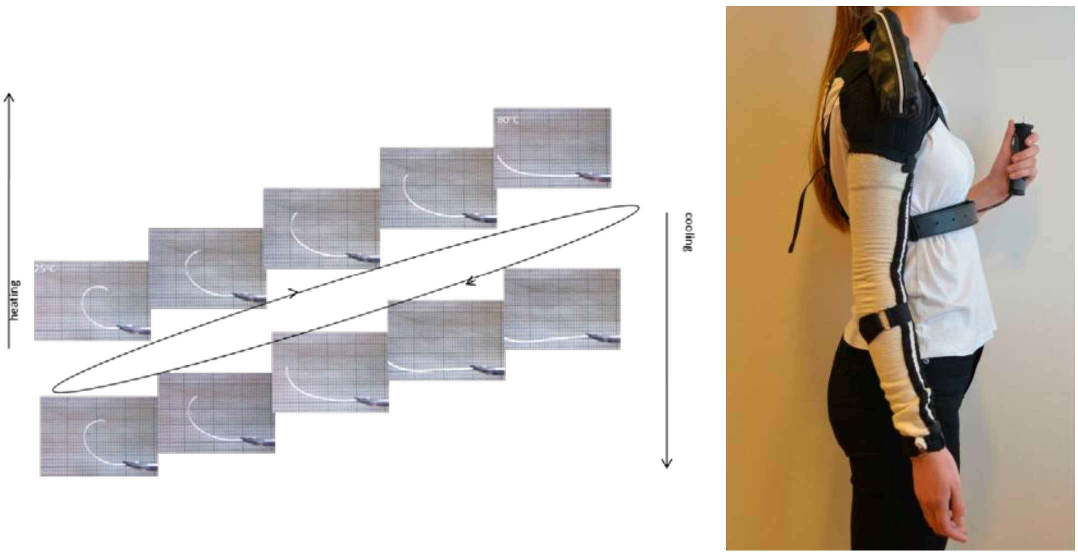

Fig. 2a) Thermotropic polymer-based fibres. Slides from Ref 2.b) Example of a dynamic textile at the garment level.

Here, a DC motor actuation mechanism is employed for an exoskeleton part; in this case allowing for the lifting of the right forearm. The system is controllable by a care giver or the user herself, as illustrated by the handle with switches on the left hand. The actuation is fully reversible. These dynamic textiles open up for a broad spectrum of applications for load carrying, human mobility, haptic communication and adaptive topology. Further development is possible in co-operation with the industry.

REFERENCES

1. Persson et al, *Actuating Textiles: Next generation of Smart Textiles.* Advanced Materials Technologies. 2018, vol.3, issue 10 (Special Issue: Electronic Textiles)
2. Persson et al. *Thermotropic textile structures,* Fiber Society Conference October 23-25, 2013 Madren Center, Clemson University Clemson, South Carolina, USA 2013

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