

# Lightweight, flexible and smart protective clothing for law enforcement personnel

September 25, 2017

## Scope of the project

SMARTPRO is an EC-funded project, implemented between April 2014 and September 2017, aiming to develop optimized protective textiles and apply innovative surface treatments to improve their performance on an areal density basis. Thus, fewer fabric layers would be required, resulting in increased flexibility and reduced weight of the armour. Main parameters considered also include protection of vulnerable parts other than the torso, physiological comfort and ergonomic design. Additionally, smart systems, namely heart rate sensors, gas sensors and textile antennas were developed and integrated in body armours to increase users' awareness

*The project brought together 10 partners from 5 EU countries:*

- MIRTEC S.A., Greece – Lead partner
- LEITAT, Spain
- Next Technology Tecnotessile, NTT, Italy
- Foundation for Research & Technology Hellas (FORTH), Greece
- Kostas SIAMIDIS, Greece
- Institut für Textiltechnik of RWTH Aachen University, Germany
- BCB International Ltd, UK
- SOLIANI EMC SRL, Italy
- E. CIMA SA, Spain
- Department D' Interior- Generalitat de Catalunya, Mossos d' Esquadra, Spain



## The challenge



Despite the progress made in terms of materials' development, the body armours currently used by law enforcement personnel remains bulky and rigid. Moreover, body armours have traditionally been designed to protect the wearer against ballistic threats and, thus, they provide only a limited level of protection against knives and sharp blades. Recent studies, however, reveal that stabbing has become a main cause of police officers' injuries. Therefore, there is an obvious need to develop materials that combine ballistic and stab protection, while retaining their flexibility and low weight.

## Overview of the project

SMARTPRO was structured in 8 work packages. WP1-WP6 were the technical WPs, while WP7 was devoted to the dissemination and exploitation of SMARTPRO's results and WP8 to the administrative management.

A key task, implemented early in the project (WP5), was the **validation of users' requirements**. This was performed through a questionnaire survey and a dedicated workshop with end-users. According to the results the end-users require **ballistic protection of Level IIIA and stab protection of Level 1 (according to NIJ standards), with a maximum panel weight of 5.72 kg/m<sup>2</sup>**.

**WP1 "protective textiles & advanced composites structures"** aimed to develop basic protective textiles to be used in the panel and advanced composites in the form of scales for impact protection, required by public order officers (riot police).

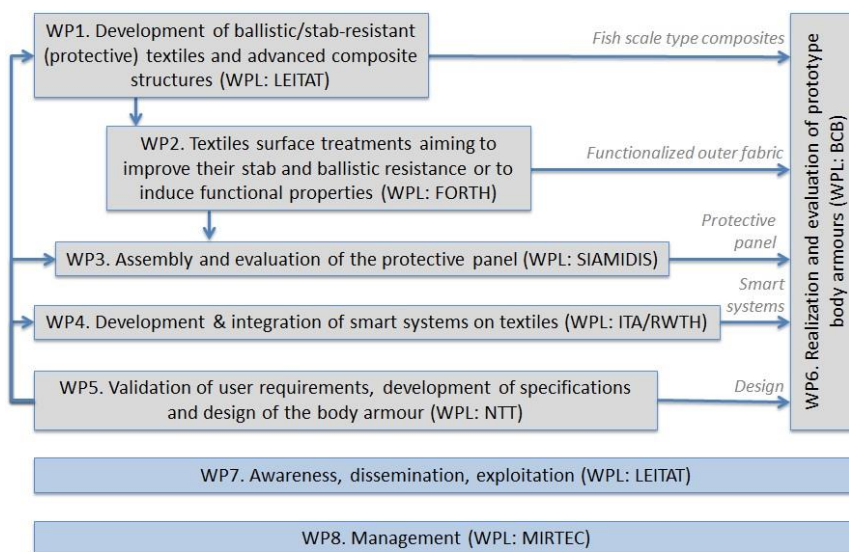
**WP2 "textiles surface treatments"** focused on the development of novel surface treatments and their application on the basic protective textiles to enhance their protective properties. In parallel, a photocatalytic polymer (SPEEK) was produced to be applied on the outer fabric of the armour's carrier to endow self-cleaning and de-polluting properties.

Next, in **WP3 "assembly and testing of protective panels"**, treated and untreated textiles were appropriately combined in panels which were tested in terms of ballistic & stab resistance. Despite the challenge of combining both protective properties, **we managed to develop panels fulfilling the ballistic and stab protection requirements with a weight very close to the target (5.76 kg/m<sup>2</sup>)**.

Parallel to the above, **WP4 "smart systems"** dealt with the development of heart rate sensors, miniaturized nanowire gas sensors and textile antennas, that can be integrated in the body armour to increase users' awareness, without restricting their tasks.

Since the acceptance of the armours by the users strongly depends on their **design**, this was the focus of a specific Task (WP5). An optimized design was proposed for public order and special units' officers, while for patrol police no interventions were made, as the participating end-users are fully satisfied with the design of currently used armours.

Finally, in **WP6 "prototypes"**, prototype body armours were manufactured and delivered to the end-users for evaluation in terms of comfort and ergonomics.



## Protective materials and panel

A key objective of SMARTPRO was the development of lightweight protective panels providing both ballistic (Level IIIA) and stab (Level 1) resistance. To reach this objective, the consortium followed a bottom-up approach, starting with the selection of basic fabrics, their surface treatment to increase their protective efficiency and the assembly of alternatively treated fabrics in panels, as described in the next sections.



### Protective textiles selection

In the frame of SMARTPRO it was decided to use Kevlar® for the manufacture of the basic protective textiles, considering the results of a market survey as well as the limitations set by proposed surface treatments. A series of woven Kevlar® fabrics were produced and characterized. At the end, a **plain weave Kevlar® fabric weighing 200 g/m<sup>2</sup>** was selected as the basic protective textile.

### Surface treatments to increase protective efficiency

Alternative surface treatments were developed and applied on the aforementioned basic protective fabric. The aim was to enhance the performance of the fabric, which would allow using fewer layers and, thus, developing a lighter panel. The treatments proposed and studied in SMARTPRO include application of:

- **Shear thickening fluids**
- **Dilatant polymers**
- **Ceramic coatings** by thermal spraying
- **Carbide and graphene-coated carbide particles**
- **Crosslinkable, side-functionalized aromatic polymers**
- **Graphene coating**

### Assembly of the protective panel

Following the application of alternative surface treatments, resulting textiles were selected, combined and assembled to develop panels which should provide Level IIIA ballistic resistance and Level 1 stab resistance, while weighting 5.72 kg/m<sup>2</sup> or less. The assembly is itself a challenging task, as various parameters have to be defined,

e.g. the type and number of fabric(s) layers, the assembly sequence (i.e. which fabrics are on the strike face and which are close to the body) and the sewing pattern. A key consideration when aiming at both ballistic and stab resistance is to combine rigid layers (generally effective in inhibiting penetration by sharp blades, i.e. stab protection) with more flexible ones contributing to energy dissipation and, therefore, enhancing the ballistic resistance of the panel. Accordingly, most of the panels developed in the project consisted of treated layers in combination with untreated ones, the latter constituting the more flexible section of the armour.

### Testing of the panel

**Ballistic tests** were performed according to the NIJ 0104.4 standard with a 9-mm caliber FMJ (124 g) at a velocity over 435 m/s.

**Stab resistance** was assessed according to the NIJ 0115.0 standard under the conditions for protection Level 1.

## Results of panel testing

Among the panels developed and tested, several passed either the ballistic or the stabbing test but failed the other, while only **two panels successfully passed both tests**. In fact, combining both protective properties proved to be quite challenging, due to the different impact mechanisms. Some of the most promising panels are presented in the **Error! Reference source not found.**, where green indicates

Type of fabric layers	Weight (kg/m <sup>2</sup> )	Ballistic test	Stabbing test
Untreated + alumina coated	5.70	no perforation BFS: 28/39 mm	24J → 45 mm
Untreated + graphene coated	5.74	no perforation BFS: 32/35 mm	24J → 44 mm
Untreated + alumina coated + graphene coated	5.55	perforates	24J → 6 mm 36J → 8 mm
Untreated + treated with nanofibers, SiC, PU	5.76	no perforation BFS: 26/30 mm	24J → 6 mm 36J → 8 mm
Untreated + treated with crosslinked aromatic polymer	5.72	no perforation BFS: 31/38 mm	24J → 42 mm
Untreated + treated with crosslinked aromatic polymer	6.00	no perforation BFS: 27/27 mm	24J → 2 mm 36J → 3 mm

successful result and red indicates failed test.

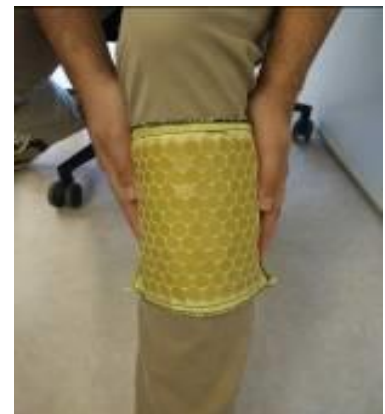
## *Scale composite for impact protection*

Here we focused on using composite materials in the form of scales, considering that scales geometry allows flexibility, even when using rigid materials. Following an investigation of the protective scales geometries and the production of prototypes by 3D printing, the hexagonal structure was selected, since it provides the optimum balance between flexibility and protected area.



Next, different composite materials were manufactured using Kevlar®, carbon and hybrid fabrics as reinforcement to select the optimum material for the scale composites. Composites containing 4 to 10 fabric layers were manufactured using epoxy resin infusion and compared in terms of cost, nominal weight, thickness and penetration force.

Optimized composite materials in terms of impact protection were manufactured and the hexagonal pattern was created in the specimens through milling or water jet cutting.



## Armours' carriers

In SMARTPRO, body armour carriers were developed for patrol officers, as well as for riot police and special units' officers, considering the tasks performed by each group and the respective users' requirements. It is worth noting that end users were actively involved in the design of the body armours since early in the project by providing guidelines to the manufacturers and evaluating early prototypes developed as design demonstrators.

### Patrol officers' body armour



- The design of patrol officers' armour carrier is the same as the one currently used by patrol officers of Mossos d'Esquadra, since it totally satisfies the end users, who had no requests for further

adjustments. The prototype was kindly manufactured by FECSA, using materials supplied by consortium partners. In particular, a 3D knitted polyester fabric was used as a liner to facilitate air circulation and enhance comfort properties. The outer fabric of the carrier is Taffeta Polyamide cordura that has been surface treated with SPEEK/PVA (photocatalyst) to achieve self-cleaning and de-polluting properties. The effectiveness of SPEEK/PVA as a photocatalyst was confirmed by EPR/FT-IR studies, while degradation tests carried out on a model dyestuff and an halogenated gas confirmed that the photocatalyst is able to degrade organics.

### Special units' and riot police body armour

A modular body armour carrier was designed and developed for riot police and special units' officers. This is a full 360 degrees' modular armour carrier vest, capable of holding front and rear soft armour inserts and hard plates. It can adopt on neck protection, throat and shoulder soft armour brassard protective panels. The system has drop down, integrated front groin and rear Coccyx protection, making this a versatile combat armour carrier system. Each part has a Velcro opening to insert the protective panels. The protective plates can be inserted in the vest pockets by openings on the left or the right of the vest. On the rear, the vest carries two rescue grab handles for casualty evacuation.



## Smart systems

To increase awareness of the end-users, smart systems (i.e. heart rate sensors, nanowire gas sensors and textile antennas) were developed and integrated in the armours, to act as alert systems.

### Heart rate sensor

The heart rate sensor acts to detect major injuries of the wearer. The main work here was focused on textile electrodes that are integrated in the undergarment of the user. These electrodes have to provide continuous skin contact, low surface resistance and textile yet machine washable characteristics.

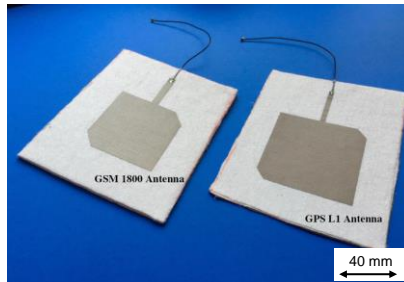


Textile electrodes with white PES non-woven, PU coating & press fastener pin on the outer side (left) & moss-embroidered terry-like inner side (right)

### Textile antenna

For on-body use, planar antennas with ground plane such as patch antennas are the most suitable topologies since they reduce the radiation in the direction of the body. Frequencies, materials, designs and production technologies

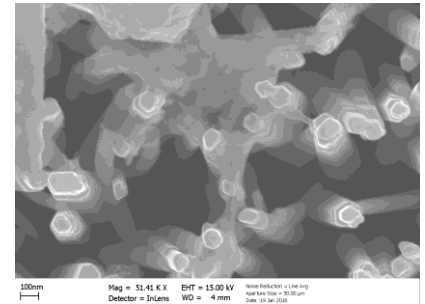
were identified, evaluation of the HF characteristics of the antennas was initiated and the influence of their performance under bending conditions was evaluated, with overall satisfactory results.



Textile GSM and GPS antennas with connector cables

### Nanowire gas sensors

The work performed in SMARTPRO pursued rational synthetic routes for controlled growth of nanowire-based arrays, which would demonstrate high performance in specific gas sensing (CO). ZnO NW arrays were grown by hydrothermal synthesis. The method is fully controllable and reproducible. A home-made set-up was developed to characterize the ZnO-based nanomaterials grown as gas sensors. The results demonstrate that the developed materials exhibit far better sensing performance for CO detection in comparison to literature data, as regards both the operation temperature and the sensitivity parameter.



SEM image of the ZnO film area where the Au electrode has been deposited

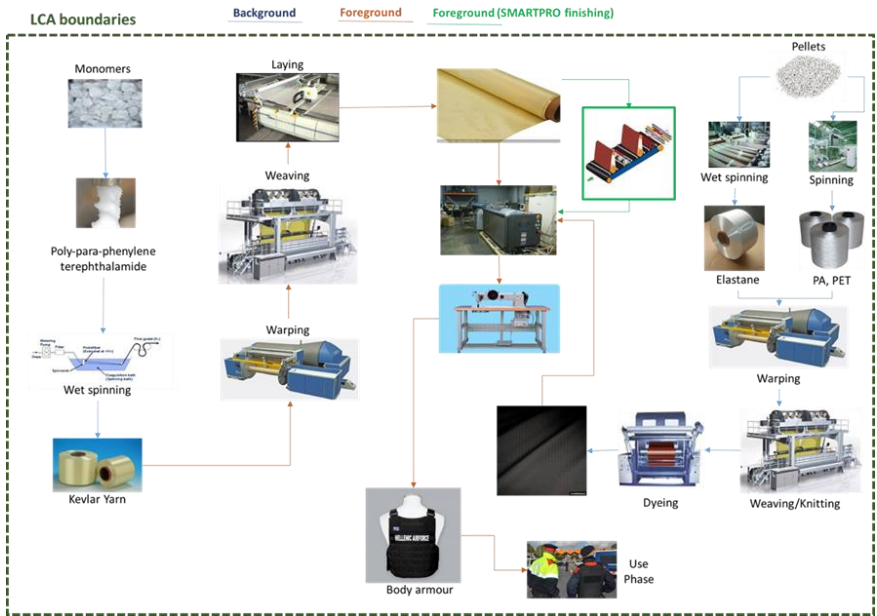
### Integration of smart systems

To assure functionality even in adverse meteorological conditions (e.g. rain), water protection of the smart systems was carried out. The textile antenna was encapsulated and integrated on the highest position in the body armour and electronic components (PCBs) were connected. The miniaturized gas sensor was placed in a 3D printed housing and integrated in the armour (close to the respiratory system) using Velcro that allows the system to be easily extracted if needed.



## LCA & LCC

The environmental impact of the body armours developed in SMARTPRO was computed using a Life Cycle Assessment (LCA) approach. Since the production of high-performance Kevlar® yarns is the single factor contributing the most to the environmental impact of the armours, it was concluded that reducing the number of fabric layers in the panel, as proposed in SMARTPRO, may lead to significant environmental benefits.



In parallel, a preliminary cost analysis indicated that the newly developed armours are

competitive to currently used ones in terms of cost.



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