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STATE-OF-THE ART REPORT

context

Smart textiles for automotive and aeronautic applications (WG2)

EUROPEAN COOPERATION IN SCIENCE & TECHNOLOGY

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AUTHORS

Luminita CIOBANU, Gheorghe Asachi Technical University of Iaşi (Romania)
Raul FANGUEIRO, University of Minho (Portugal)
Dorin IONESI, Gheorghe Asachi Technical University of Iaşi (Romania)
Adnan MAZARI, Technical University of Liberec (Czech Republic)
Ioannis SYMEONIDIS, Hellenic Institute of Transport (Greece)

With the collaboration of

ABSTRACT

The aim of this document is to provide information on the state-of-the-art related to the topics covered by each working group within the CONTEXT project. It provides information on materials and technologies used to develop smart textiles with targeted performance, general applications of smart textiles in the field, case-studies on the use of smart textiles, opportunities for smart textiles considering the needs of each field, trends on the development of smart textiles in terms of market and technical expectations.

This paper gives an overview of the potential of smart textiles for automotive and aeronautic applications, ongoing developments, state-of-the-art products and future developments.

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1. INTRODUCTION

According to the European Standard CEN/TR 16298[1] "Smart textiles are the textile materials or textile systems that possess supplementary intrinsic and functional properties that are not normally associated with traditional textiles". In other words, smart textiles can be defined as textiles that are able to sense and respond to changes in their environment.

Smart textiles can be passive and active. Passive smart textiles have the ability to change their properties according to an environmental stimulation (temperature, pressure, light, etc.). Shape memory materials, hydrophobic or hydrophilic textiles, etc. are part of this category. Active smart textiles are fitted with sensors and actuators in order to connect internal parameters to the transmitted message. They are able to detect different signals from the environment such as temperature, light intensity and pollution to decide how to react and finally to act using various textile-based, flexible, or miniaturized actuators (textile displays, micro vibrating devices, light-emitting diode (LED), organic light-emitting diode (OLED)). The "decision" can occur locally in case of embedded electronic devices (textile electronics) to smart textile structures or remotely in case the smart textile is wirelessly connected to clouds containing data base, servers with artificial intelligence software, etc.[2]

Smart textiles are used in a wide range of applications in various fields like medicine, personal protection, transportation, defence, among many others.

Figure 1 - Smart textile communication capability [3]

Figure 2 - Smart textile with lighting capability[4]

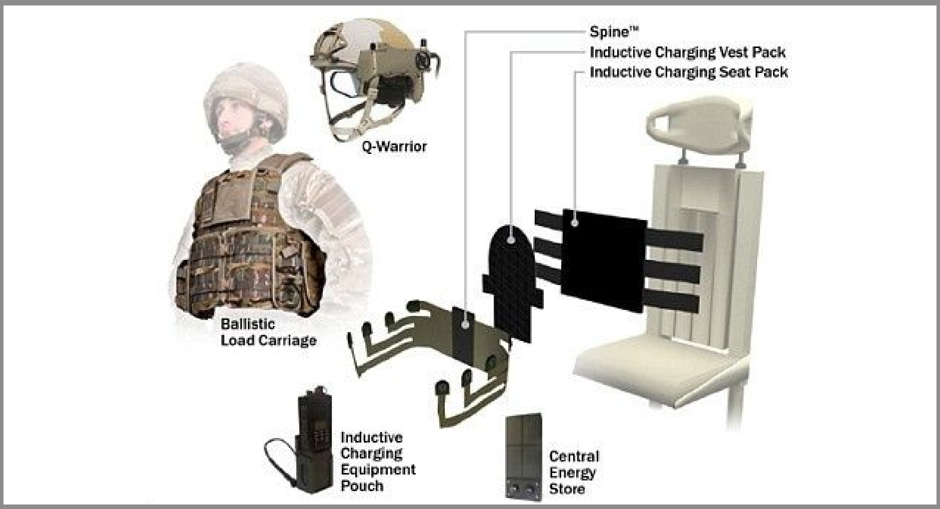

Figure 3 - Smart textiles in protective systems for soldiers[5]

Figure 4 - Smart textiles in car interiors[6]

The transportation sector, including ground transportation (automotive and railway) and aerospace (airplanes, satellites, spaceships, etc.), is a very important field of applications for smart textiles. Today's most important target is the decrease of the weight of vehicles and planes in order to improve their efficiency and behaviour. Textile composites are rapidly developing, and textile manufacturing. technologies such as weaving, knitting and braiding or even hybridized approaches are increasingly used for 3D-composite reinforcement design and manufacturing. Yet, composite parts and particularly structural ones have to be monitored in real time in situ for security purposes and predictive maintenance. Therefore, smart and communicative composites with embedded sensors, connected to supervision devices, are able to monitor in real time the solidity of the structure and to alert in case of problems (predictive maintenance) will be a reality in the next few years.

From the beginning of industrialization, metals, especially steel and cast iron represented the main raw materials used for industrial activities, including car manufacturing. Currently, the trend within the European Union is the reduction of the demand for materials from high material-consuming industries, as well as a cut-down in the volume of materials used. The recommendations made at EU level regarding the economic, social and environment policies adopted within the frame of Lisbon Strategy refer to: clean energy, sustainable transport, sustainable production and consume, public health, improved management of the natural resources, social inclusion, the fight against global poverty[7]. The development of lighter weight, more resistant and more durable materials is an answer to these problems.

Generally, a composite material is made of distinct materials, that together act in a different way than when considered separately. There are a lot of examples of composite materials, both natural and synthetic, from the human body, to buildings, airplanes and so on. Most comprehensive definition of the composite materials that characterises their nature is given by P. Mallick. According to Mallick (1997, a composite is a combination of two or more chemically different materials, with an interface between them. The constituent materials maintain their identity in the composite material (at least at macroscopic level), but their combination gives the system properties and characteristics different from those of each component. One material is called matrix and is defined as the continuous phase. The other element is called reinforcement and is added to the matrix in order to improve or modify its properties. The reinforcement represents the discontinuous phase, distributed evenly in the matrix volume).[8]

There are several options for reinforcement and matrix that are taken into consideration based on the mechanical requirements specific to the application.

The development of textile reinforced composites (TRCs) with resin matrix is based on the desire to produce improved materials, with tailored properties. The textile material gives the ensemble strength, while the matrix ensures the composite unity and transmits the strains. The advantages of the textile reinforced composites are:

- controlled anisotropy of the textiles which means that their structure materials can be designed so that the fibres are placed on preferential directions, according to the maximum strain;
- the use of textile reinforcements allows to obtain a better weigh/strength ratio compared with the classic materials, such as steel;
- textile materials maintain their integrity and behaviour under extreme conditions – for example, they do not corrode in an outdoor environment, nor vary their dimensions when there are significant temperature variations, nor are they sensible to electro- magnetic fields;
- TRCs present an improved fatigue life.

2. TEXTILES AND COMPOSITES IN VEHICLES

Today's life style leads to the fact that people spend much more time in the vehicles that are sometimes used as places to work, eat, sleep, etc. Therefore, the safety and comfort of a conveyance are of paramount importance, which contributes to the design, functionality and cost-effectiveness of the vehicle interior.

Textiles in transport vehicles have multiple functions and can be summarized as follows:

- they provide comfort during the long sitting in the same position. Textiles are used for filling spaces and cladding of seat constructions (made of a metal, plastic and wood) with composite materials (woven fabric + polyurethane foam + knitting fabric) and thus contributes to its ergonomic design
- they provide passenger safety (seat belts and airbags)
- they ensure the protection of transport vehicles (shields and reinforcements for tires, reinforcement in the walls of the transport vehicles, air and fluids filters, external airbags)
- they provide noise and vibration reduction in vehicles (multilayer materials for coating the interior).

Textiles in the transport vehicles, beside the basic physical-mechanical (strength, abrasion resistance, pilling) and thermo-physiological properties (comfort), must meet a number of other specific properties (resistance to sunlight and UV radiation, reduced flammability, odour free, antistatic, soil resistance) and at the same time be stable under the external temperature and humidity conditions (temperature of - 20 to + 100°C and humidity of 0-100%)through the entire vehicle life time. Textiles must also meet the high requirements for attractiveness following global trends in design[9].

Polymer composites are materials defined by the combination of a polymer matrix (resin, either thermoset or thermoplastic) and a reinforcing agent, mainly fibres (usually carbon, glass or natural fibres). As a result, they are often referred as Fibre-Reinforced Plastics (FRP). In addition, FRP composites may contain fillers, modifiers and additives that modify the properties and improve the performance of the composite material, contributing to cost reduction.

FRP composites are anisotropic instead of isotropic like steel and aluminium. Whereas isotropic materials present uniform and identical properties in all directions, FRP composites are directionally dependent, meaning that the best mechanical properties are in the direction of the fibre placement. In many structures and components, stresses and loads are different for different directions. As a result, FRP composites allow a more efficient structural design. Other benefits include a low weight, high strength-to-weight ratio, corrosion and weather resistance, long-term durability, low maintenance and dimensional stability.[10]

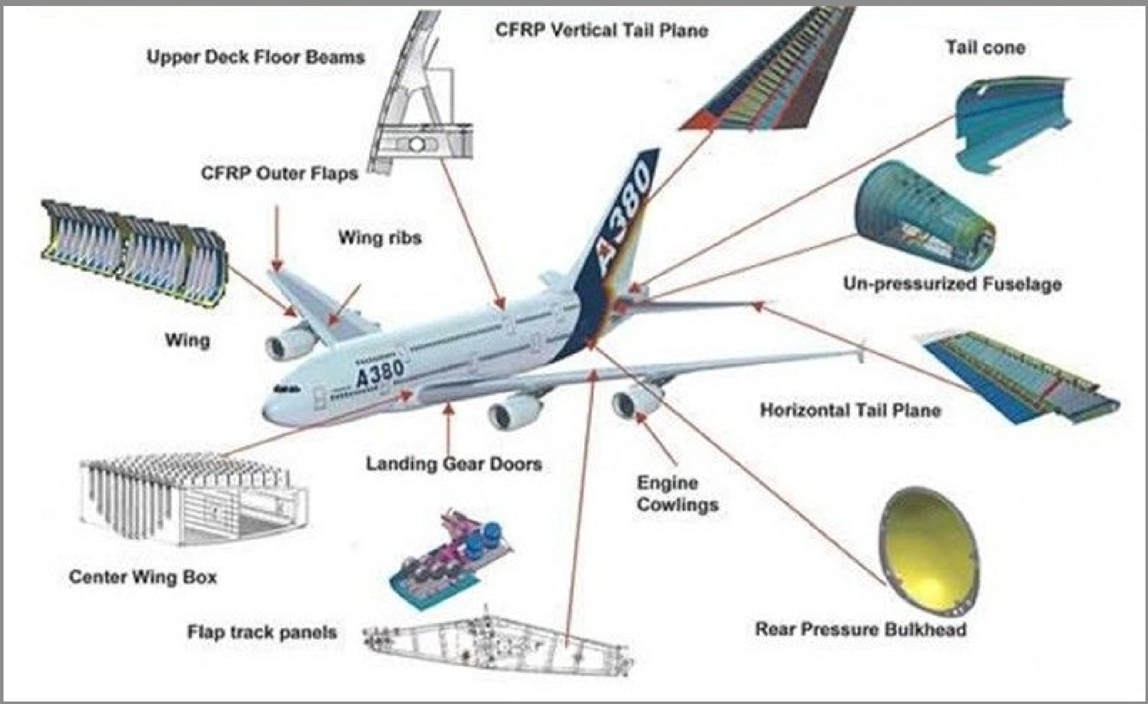

Figure 5 - Composite materials used in A380 [11]

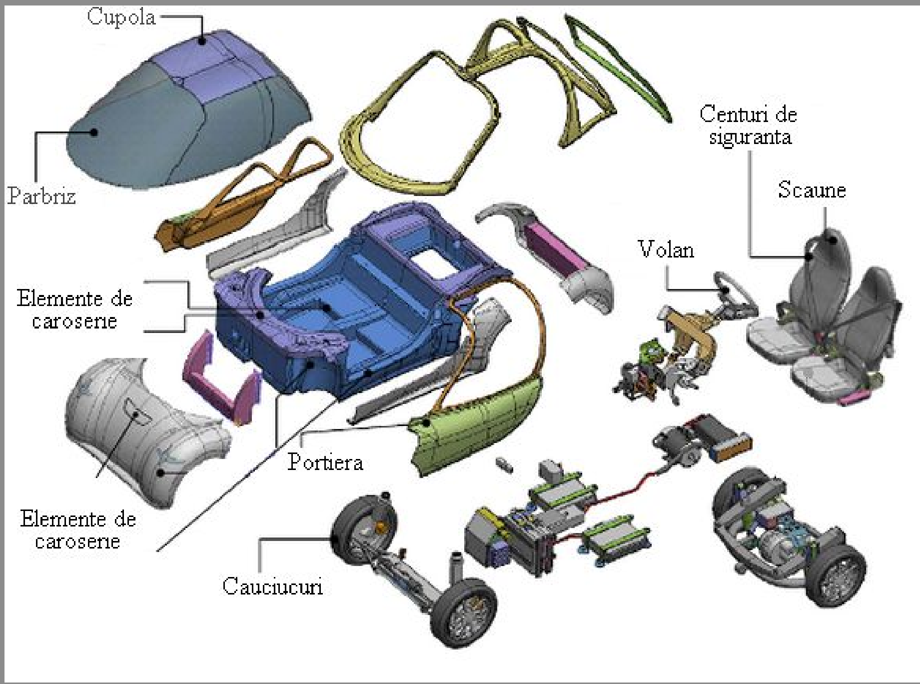

Figure 6 - Composite materials in cars[12]

The demand for weight reduction is driven by the demand for better fuel efficiency and reduced emissions in order to comply with EU legislation (from <130g CO_2/km in 2015 down to <95g CO_2/km by 2021). Composites can offer lightweight benefits from 15-25% for glass-fibre reinforced composites (GFRP) to 25-40% for carbon-fibre reinforced composites (CFRP) in comparison to other structural metallic materials that are presently dominant, such as steel, iron and aluminium. The benefits of light-weighting can be translated into potential savings of 8 million tons of CO_2 per year in the EU wide vehicle fleet3, calculated using a theoretical 33% weight reduction on a 10% volume of the entire EU fleet. Improving the value at end-of-life of composites through high value recycling could help to improve the overall LCA score of composites, but remains challenging. This is especially important given the present EU end-of-life directive for cars (valid since 1st of January 2015), which stipulates mandatory reuse and recycling of 85% of the vehicle (and does not consider 'energy recovery' of polymers to be recycling). Bio-based matrix materials and fibres can help in reducing the environmental footprint of composites. For these materials to be widely used, important barriers with regard to their cost effectiveness and their mechanical performance need to be addressed. To enable larger scale adoption of FRP, methods to determine damage to composite parts over the lifetime of the vehicle also need to be developed.[10]

3. SMART TEXTILES AND COMPOSITES IN VEHICLES

According to Mordar Intelligence, the market for smart textiles for transportation systems was valued at 341,3 million euros, in 2019, and is expected to reach a value of 767,2 million euros, by 2025, at a CAGR of 14.23%, during the forecast period, 2020-2025. Cars, boats, aircrafts and trains are great consumers of these materials.

The technological advancement in the electronics industry has changed the way we do and perceive things. The Internet of Things has connected everything. Smart fabrics are an important part of this technological advancement and may play a very crucial role in the future, with large applications in the transportation industry. With the miniaturization of electronic components, coupled with the emergence of advanced polymers, is driving the market forward.

The materials of our surroundings are being "intellectualized". These materials can interact, communicate and sense. Polymeric or carbon coated threads, conductive yarns, conductive rubber, and conductive ink have been developed into sensors or used as an interconnection substrate. Conductive yarns and fibres are made by mixing pure metallic or natural fibres with conductive materials. Pure metallic yarns can be made of composite stainless steel or fine continuous conductive metal-alloy combination of fibres with conductive materials can be completed by the methods namely: fibres filled with conductive material (e.g., carbon -or metallic particles); fibres coated with conductive polymers or metal and fibres spun with thin metallic or plastic conductive threads. Metallic silk, organza, stainless steel filament, metal clad aramid fibre, conductive polymer fibre, conductive polymer coating and special carbon fibre have been applied to the manufacture of fabric sensors.[13]

Besides, smart textiles applied to vehicles can include a large number of advanced smart materials including:

- Metal fibres for electrical conductivity with applications in piezoresistive sensors, health monitoring and heating systems;
- Conductive inks for colour change, conductive surfaces, electronic circuits, de-icing systems;
- Inherently conductive polymers for sensing devices including deformations and for energy harvesting and storage systems;
- Electrically conductive textiles to functionalize and reinforce composite materials and for interior covers with ability for heat dissipation and sensing capabilities;
- Shape memory materials for deformations recover and dynamic structures;
- Coating with nano-particles to functionalize textile surfaces and composites for antibacterial, antiviral, colour change, heat dissipation and absorption, sensing;
- Chromic materials with the ability to change colour according to different external inputs such as UV light, pressure, electrical current, moisture;
- Phase change material with the ability for thermal management in textiles and composites;
- Optical fibres for sensing systems and data transmission.

The combination of smart textiles with polymeric matrices, such us epoxy or polypropylene, may lead to composite materials with very interesting performance and functions. The transportation industry is among the largest consumers of advanced composites due to the low weight and high mechanical properties of these materials such as static strength, fatigue performance, fracture toughness, damage tolerance, high impact resistance, and resistance to high temperatures. In addition, composite components can be produced with fewer joints and rivets, leading to lower susceptibility to the structural fatigue. For example, in the aerospace industry, weight reductions of up to 40% could be achieved when aluminium is replaced by composite materials. A reduction of 1 kg in weight corresponds to 40-450 euros fuel saving depending upon the type of aircraft and fuel prices.

Many metallic structural and non-structural parts used in the transportation industry could be replaced by textile-reinforced composites where each production step has to be monitored to obtain high tech products.

These composites have to be produced to meet technical performance specifications, weight reduction, recyclability and market requirements[14-23]. Composites made from a polymeric matrix and a fibrous reinforcement have been increasingly studied during the last decade due to their remarkable features such as corrosion, chemical and impact resistance, dimensional stability, design flexibility, suitable electromagnetic properties, temperature tolerance, etc.[24, 25] In composite applications, the low material density is of environmental interest because fuel consumption and CO2 emissions are directly related to vehicle weight. [21-26] The usage of smart textile structures in order to realize textile fibrous sensors compatible with composite technology is a very promising solution for in situ structural health monitoring of composite parts. As mentioned before, such smart materials could be made by coating or treating textile filaments, yarns, or fabrics with nanoparticles or conductive and semi-conductive polymers, giving them specific performance characteristics.

Smart textiles play a significant role in the European textile sector and have helped the textile industry in its transformation into a competitive knowledge-driven industry. These kinds of textiles combine knowledge from many disciplines with the specific textile requirements.[27] These sensors perform a dual function inside a composite. After integration in the reinforcement, they act as a part of structural material and have actuating and sensing capabilities. Their working principle originally relied on the traditional metal-based strain gauges.[28, 29] In general, strain gauges for textiles are based on electrically resistive materials or structures whose electrical resistance changes reversibly according to an applied stress.[30, 31]

Today, modern aircrafts use composite materials up to 50% by their weight.[32] The composites are used in commercial and military aircrafts for several non-structural and structural parts such as spoilers, elevators, horizontal stabilizer boxes, radomes, rocket motor castings, tail sections (Airbus), rudder (Boeing 767), fuselage (V22), antenna dishes, engine nacelles, landing gear doors, engine cowls, wings (Prototype ATF, V22), cargo liners, and so on.[32] Carbon fibres dominate the aerospace sector due to their high strength/stiffness and low density. Other fibres like aramid and glass also have a limited usage, but low strength and high density of glass fibre limit its usage in aircraft structures, whereas aramid fibres have the moisture absorption problem.

Regarding the matrix systems, epoxy resin is the most preferred matrix material due to its high mechanical properties and durability. Space applications of advanced composites include launch systems and self-contained space modules such as satellites, space crafts, and space stations. Composites allowed 30% weight savings when used in expendable launch vehicles (ELV) for Atlas, Delta, and Titan rocket launch systems. Composites produced with less labour-intensive techniques such as filament winding and automated tape winding proved more economical than costly joint welding of metals. Composite motor cases from carbon fibre/epoxy with high strength and stiffness provided substantial weight reductions. Nozzles such as exit cone and throat elements are composed of carbon fibre/phenolic or carbon-carbon composites to withstand hot exhaust gases of burning propellant.[32] Hubble Space Telescope contains a carbon fibre/epoxy metering truss with near-zero coefficient of thermal expansion (CTE) which provides dimensional stability required for precise alignment of the optics aboard the telescope. These trusses are also designed to cope with various compressive loads. Composites are also used in space shuttles. Payload bay doors made of carbon fibre/epoxy (T-300) composite parts provided weight savings of over 400 kg.[32]

4. APPLICATIONS OF SMART TEXTILES AND COMPOSITES IN VEHICLES

Imagine upholstery that puts on a light show in time to the music you're playing, automatically illuminates an area where you might need to clean up a toddler's spilled Cheerios, or, as seen in BMW's i Inside Future concept, be able to support in-seat audio innovations that allow each passenger to listen to something different. Smart fabrics can detect an occupant's size, weight, temperature, and even mood, counteract fatigue, insulate the occupant from ambient noise, or simply change colour.

Figure 7 - Smart textiles car seats [33]

Figure 8 - Smart textiles in upholstery - BMW. Future concept [34]

In the INSISTEX project the application of intelligent technical textiles in automobile for the increase of active passenger safety has been investigated. In this context innovative applications for the prevention of accidents has been realized by the integration of textile sensor elements into components of the automotive (seat, steering wheel, ceiling etc.). Especially applications for the recognition of the driver's condition, vigilance measurement and the recognition of the seat occupation have been considered.

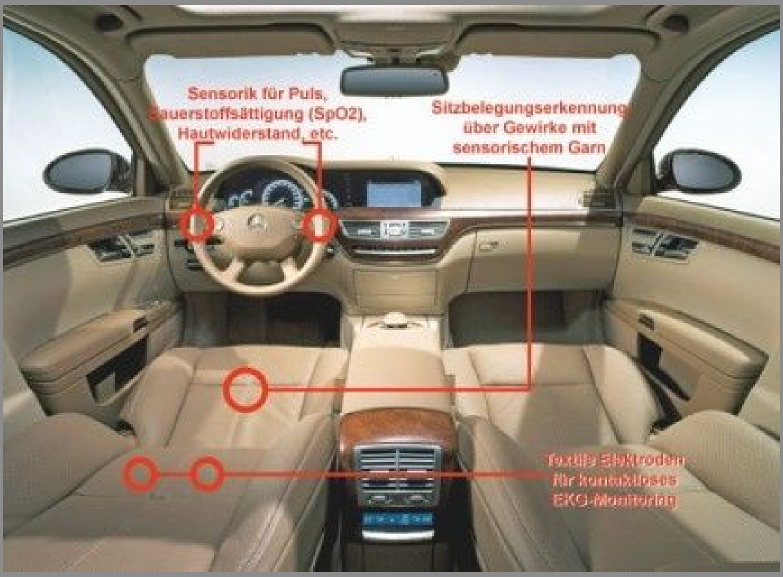

Figure 9 - Concept for textile seat occupation sensor realized by crimp interconnection (INSISTEX project)

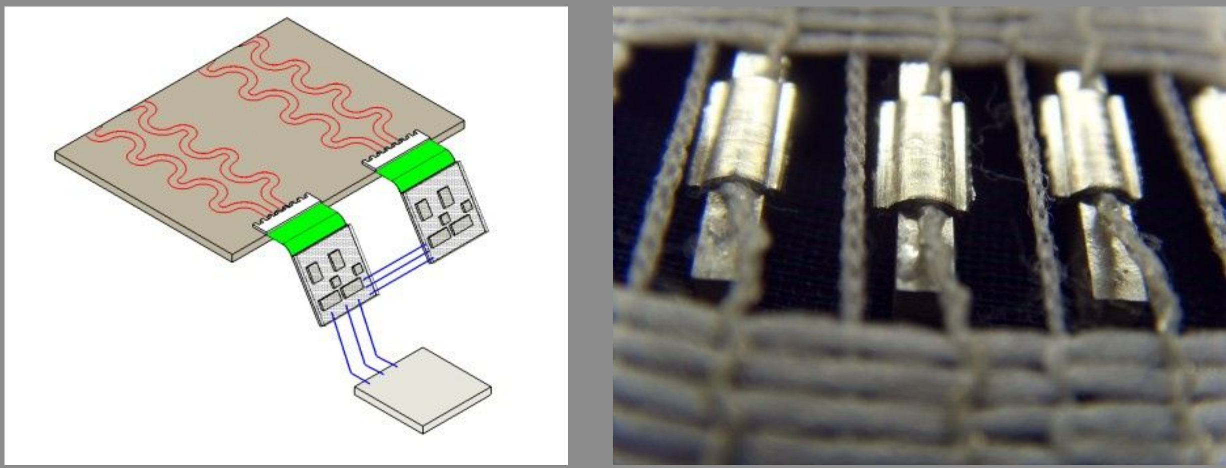

Figure 10 - Textile sensors used in the INSISTEX project

Automotive interiors offer a large range of application for smart textiles. Visibility and ambient are very important when designing car interiors.[35] Smart textiles can control the colour patterns and the level of luminosity inside a vehicle according to the needs of the passengers. For example, curtains made of electroluminescent textiles can be used in car interiors to ensure ambient light. Illumination can be produced with LEDs integrated in a conductive textile material used for headliners.

Figure 11 - Innovative AIRBUS seats[36]

Immobility of passengers is an important problem for long-distance flights, as it can affect the circulatory system and cause a large range of issues, from stiffness, swelling and general discomfort to deep vein thrombosis (DVT) symptoms.[36] In order to avoid these health risks, the UK-based design studio Layer in partnership with Airbus developed a new seat for airplanes.[37] The knitted material used for this type of seats contains a set of sensors used to detect passengers' weight, movement and temperature. The data is used by an app to adjust the optimum position of the seat so passengers will experience no discomfort during their travel. The lightweight frame of the seat is made of aircraft-grade aluminium and carbon fibre facilitates the adjustments made for the optimum seat position. The seat does not use any type of foam, increasing its level of sustainability.

An embroidery German company (Modespitze Plauen GmbH) has developed a special tailored fibre placement technique called Tailored Sensor Placement that connects conventional textiles (woven, knitted, nonwoven) made of glass, aramid, basalt or carbon with functional structures like sensor areas, feed lines and contact points. The embroidered sensor layer is integrated in the textile reinforcement.

The sensors are used to detect strain, stress, natural frequency (resistive), as well as fluid levels, proximity sensors (capacitive) and temperature (resistive). These composite materials are used for different applications - engineering, mobility sector, wind power plants, sports equipment, health/ medical devices and civil engineering.

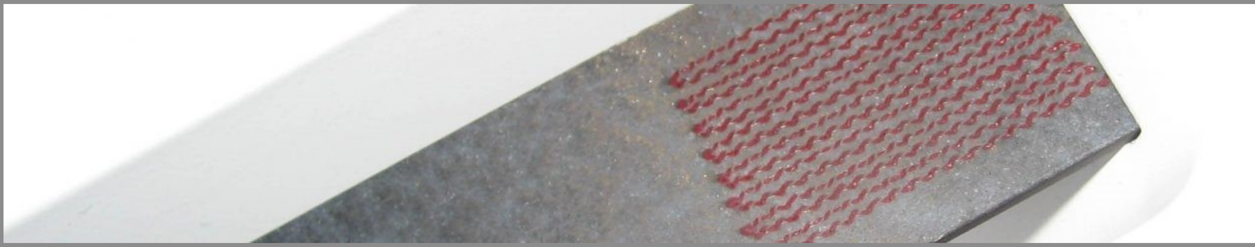

Figure 12 - Embroided textile reinforced composite sensor[38]

Intended to develop composite body panels that could store and release energy like a battery, the European Union-funded project STORAGE (2010-2013), led by Imperial College (London, UK) and Volvo Cars (Gothenburg, Sweden), demonstrated a structural supercapacitor roof and a trunk lid with supercapacitor laminates that cut weight 60% compared to existing components. The rechargeable panels comprise multiple layers of carbon fibre/epoxy insulated by fiberglass inserts (see above). Parts were made using Solvay Specialty Polymers' (Woodland Park, NJ, US) MTM47 out-of-autoclave prepreg.

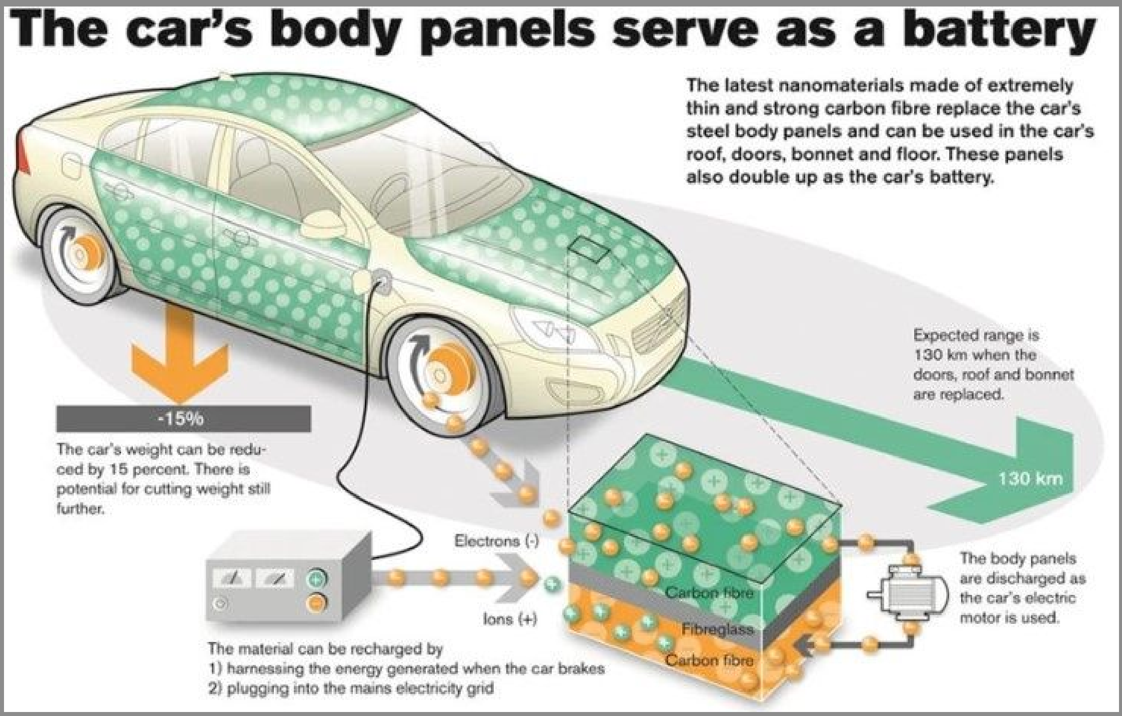

Figure 13 – Car body´s panel used as battery [39]

A variety of material approaches were investigated for efficient energy transfer, including carbon aerogel reinforcement of carbon fibres and multifunctional matrices (e.g., 50/50 weight mixtures of epoxy resin and ionic Li salt solution). Volvo claims such panels could power its S80 hybrid demonstrator vehicle's 12-volt electrical system. Project teammate Swerea SICOMP (Piteå, Sweden) has led patent applications for carbon fibre batteries.

There also has been an increase in car models with photovoltaic solar panels in the roof. "The military has been developing battery panels and embedded solar panels for years," says Gary Lownsdale, president of Trans Tech International (Loudon, TN, US). "Again, hybrid composite materials offer a lot of opportunity, for example adding carbon nanotubes and other nanomaterials. Embedding flexible electrical circuits in body panels is also an attractive development because you can get rid of the wiring harnesses and simplify the supply chain and assembly."

Smart car needs smart seats, those days are gone when basic fabric and cushion is used for the car seats, and manual adjustment for thermo physiological comfort is no more accepted as norm for automotive seating. Every driver is different and needs a completely different arrangement for seating comfort. A smart car seat which can ventilate heat up or dry the microclimate can be very important for the car users. The weight of driver and its effect the thickness of car seat cover and flow of moisture/heat is just complicated issue and if car seats can manage this automatically without any manual adjustments will be very practical for the car industry. Also informing the driver on his status, and signifying risks that can improve the safety.

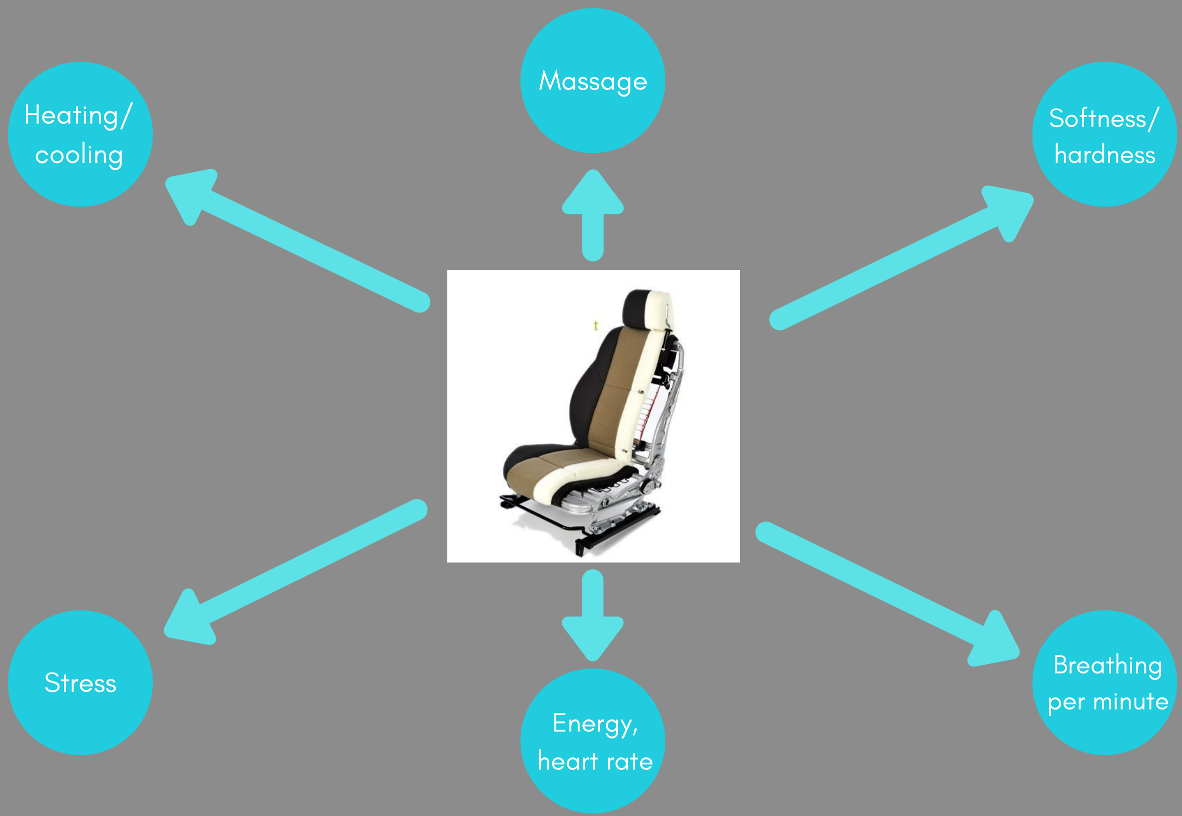

Figure 14 - Smart car seats approach[40]

Smart textiles and composites have many applications in motorcycle rider's personal protective equipment (PPE). The main requirements for impact and abrasion resistance that also offer protection from the environment, and allow comfortable riding can only be fulfilled with smart textiles with advanced properties and composite materials.

The outer shell of the helmets is commonly produced from composite materials as carbon fibre, Kevlar or fiberglass reinforced polymers in order to meet high impact strength (e.g., in exposed areas as the chin bar) and low weight requirements for safety and comfort. Advanced fabrics in the helmet liners allow better comfort, skin breathability and airflow for better thermal comfort. All helmets in EU are required to pass ECE 22.05 while an updated homologation ECE 22.06 is expected soon.

For the rider body protection, the fabrics of the rider suit offer abrasion resistance, while foams (memory or viscoelastic) offer impact protection for the important articulations without obstructing the range of motion during riding. The EN 17092 is the new homologation standard that will replace the EN13595 for the certification of impact and abrasion protection of motorcycle PPE. Integrated airbags are available in rider suits that are actuated from sensors (usually accelerometers) on the suits or the motorcycle.[41, 42] Thermal comfort, is also an important factor both in hot and cold weather conditions with fabrics that either allow the air circulation and sweat permeability or provide insulation from the external environment.

In the ADAS&ME EU funded research project sensors were integrated in the fabrics of the rider PPE to monitor the rider condition. Temperature sensors, electrodes, photodiodes and Microelectromechanical systems (MEMS) were integrated in the PPE with target the monitor of the rider health, thermal comfort, stress level and distraction.[43]

5. OPPORTUNITIES AND TRENDS

Mobility Management to Witness Significant Growth[44]:

- Mobility management in transportation comprises all the systems that allow a driver to reach their destination safely and quickly, with optimal fuel consumption, by deploying smart fabrics into the vehicle, which can enhance the vehicle features.
- With the help of these smart fabric-sensing systems installed in the interior cabins, autonomous vehicles can access real-time traffic information through their onboard navigation systems, and re-route the vehicle to a better route, to avoid traffic jams. They can also provide information on parking lots and refueling stations, which can save travel time.
- Over the next few years, due to the technological advancements in IoT, drivers would be able to access highway warnings and messages to avoid accidents. Real-time data analytics is capable of utilizing the IoT and Big Data capabilities, to enhance mobility systems and ensure concentrated device uptime. Ultimately, this can reduce costs associated with vehicle management and can benefit the transportation industry.
- With the increasing penetration of autonomous vehicles, the demand for smart fabrics may also witness an increase, driving the market forward.

Trends for Aeronautics 2050[45]:

Urban air will relieve congestion and stem rising transport costs by deploying smaller, unnamed aerial vehicles (UAVs) and air taxis for intra-and some intercity commutes. The physical infrastructure to support these new urban and regional air mobility options will include widespread networks of small, low-cost vertiports (airports for vertical takeoff and landing) intermixed with larger transportation hubs in addition to traditional infrastructure.

Most of these vehicles will not be operated by an in-vehicle pilot. Remote pilots are like to continue to operate UAVs over the next 15 to 20 years. By 2050, aerial vehicles will navigate the world using widespread AI, could-based technology and constantly updated data.

Larger-payload cargo UAVs will facilitate dynamic supply chains, reducing both inventory requirements and physical footprints of warehouses and distribution centers while lowering costs and increasing the speed of transporting goods.

Technological breakthroughs such as efficient supersonic flight will break new frontiers while remaining cost effective for specific us cases (for example, a cross-Atlantic supersonic flight at the price of today's business class fare).

Cleaner and quitter electric propulsion will power this new world. New materials and manufacturing processes will allow faster and more responsive production of vehicles, making them affordable and bringing them to market faster.

Opportunities for smart textiles and composites:

- WEIGHT REDUCTION - 10% reduction on weight corresponds to 5-7% in combustible saving;
- DURABILITY - Corrosion, fatigue, cyclic load;
- PERFORMANCE - Mechanical performance;
- FLEXIBILITY - Combination of different types of materials / Product design;
- CIRCULAR ECONOMY - Decrease the production of waste / Renewable energy and biodegradable materials;
- SUSTAINABILITY - transport systems accounts for 36,9% of the overall energy consumption / 40% reduction of gas emissions till 2030.
- MULTIFUNCTIONALITY - Smart, interactive, autonomy, safety, connectivity

6. CONCLUSIONS

The future of modern textiles in the aviation sector, in aeroplane interiors and bodies, as well as in functional clothing, will be vital for the future development of high-performance aircraft and spacecraft. Low weight, high strength, cost efficiency, ease of working with the materials, and safety are all parameters that can only be achieved using other materials with difficulty, if at all. Innovations, such as incorporating bionics into the development of new textile solutions, will open completely new solutions for engineers and scientists. Before the theory can be put into practice, the challenge of developing efficient production processes will always remain, so that ideas such as versatile spider silk can be transformed into a practical reality.[46]

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