CENTRO RICERCHE FIAT

COMPOSITES AND SMART MATERIALS:

A SYNERGIC APPROACH FOR TOMORROW'S VEHICLES

Francesco Butera

Micro & Nano Technologies
FIAT Research Centre – Orbassano

Contact: francesco.butera@crf.it

CENTRO RICERCHE FIAT

Traditional path: from aerospace to ground transportation

Today the use of composites in the aerospace market is widespread, extending beyond commercial and military aircraft to military jets, helicopters, space launchers and satellites.






Despite the rapid development of composite materials within the aerospace industry, the use of composites for ground transportation was slow to take off…

- **Costs of materials and processes are prohibitive**
- **The time of process is too high and then it is incompatible with mass production**
- **High costs and time of manufacturing required for the improvement in performance is justified only for <u>"low volume" and "high added value" products (i.e. sport cars)</u>**

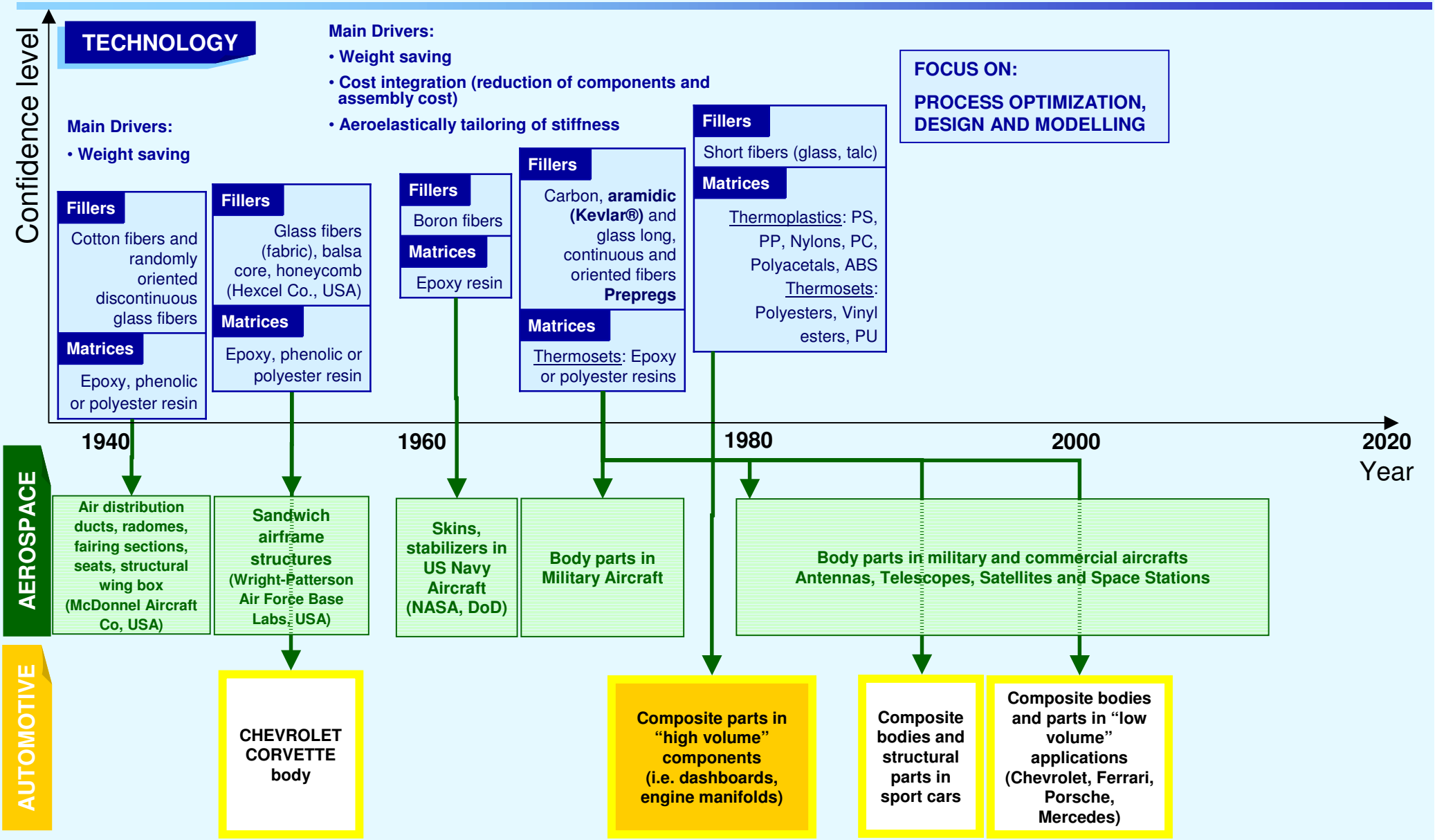
Mercedes-Benz SLR McLaren

Ferrari Enzo

Porsche Carrera GT

CENTRO RICERCHE FIAT

Evolution of composites and relative applications



CENTRO RICERCHE FIAT

Evolution of vehicle weight

1978 – FIAT Ritmo

Weight 900 Kg

2002 – FIAT Stilo

Weight 1400 Kg

Weights of critical parts

Engine	+ 20 % (300 Kg)
Body and Chassis	+ 30 % (380 Kg)
Electronic parts	+100 % (100 Kg)
Cabin components and comfort parts	+100 % (310 Kg)

In the last 2 decades the weight increase of vehicle structure was less than the weight increase of electronics and comfort parts.

Today weights of cabin components and comfort parts are similar to the body and chassis weight, therefore a great weight reduction is achievable working on functional components

THE NEW PARADIGM IS:

REDUCING THE WEIGHT OF FUNCTIONS THINKING BEYOND THE ADD-ON APPROACH !

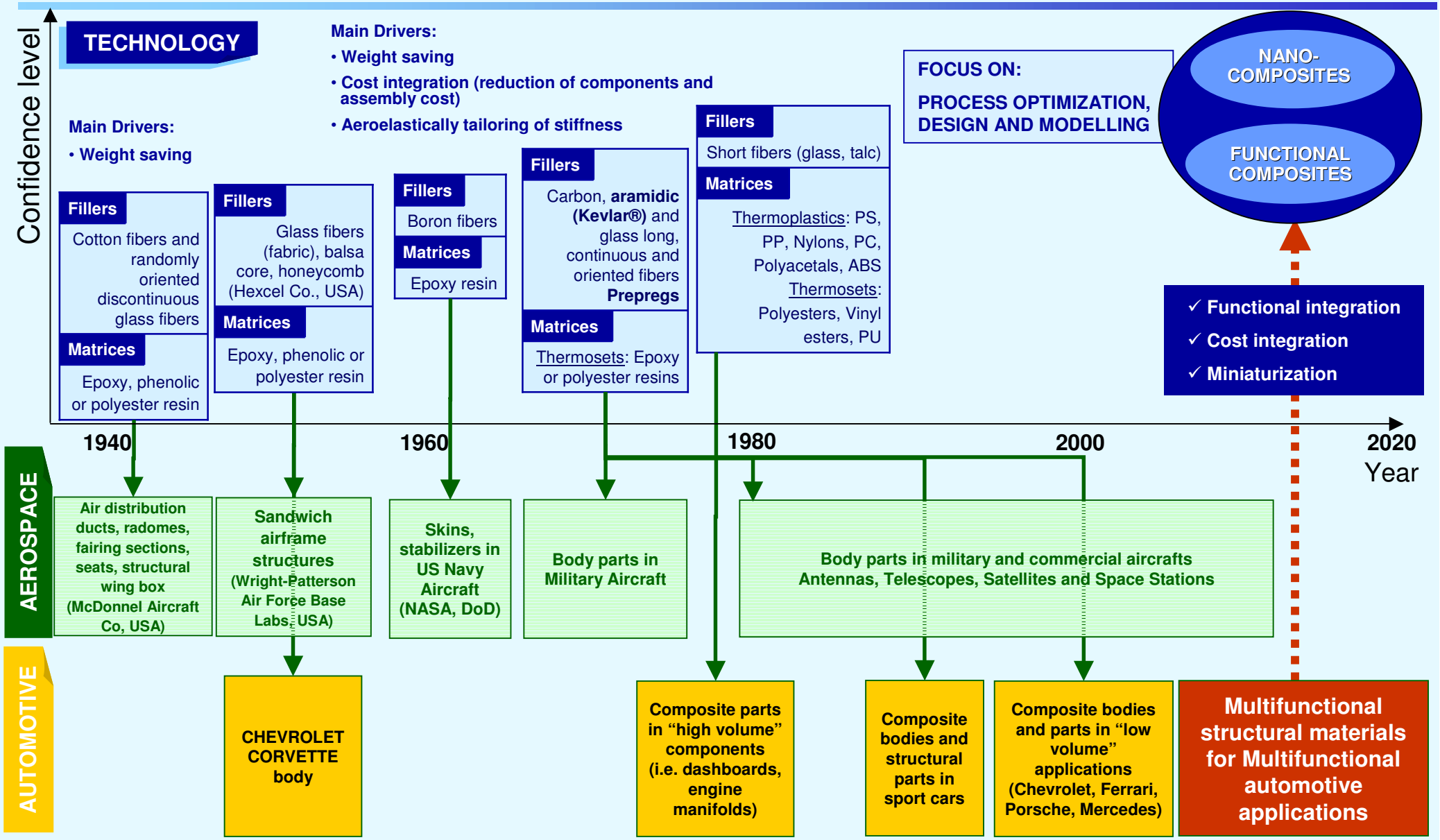
COMPOSITES WILL HAVE A BRIGHT FUTURE IN CARS IF:

1. Integrate new functions in structure, such as sensors, actuators and electronics
2. They consist of:
    - Cost effective smart materials (Shape memory 1,5 Euro/m, Piezo films 1 Euro/patch …)
    - Cost effective matrix (Thermoplastics or thermosets)
    - Cost effective processes

MULTIFUNCTIONAL COMPOSITES COULD REDUCE VEHICLES WEIGHT BY 20% OWING TO THE REDUCTION IN HEAVY MECHANICAL AND ELECTRONIC DISCRETE COMPONENTS

CENTRO RICERCHE FIAT

Multifunctional composites: a reverse path ?

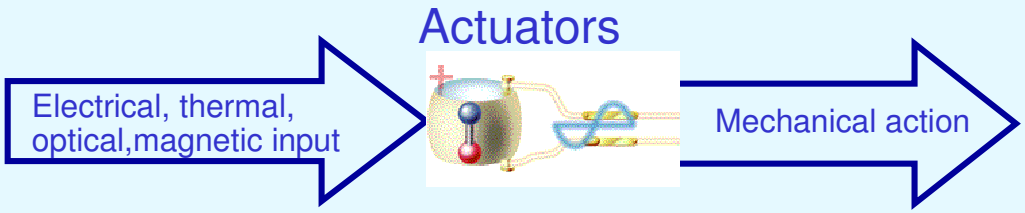


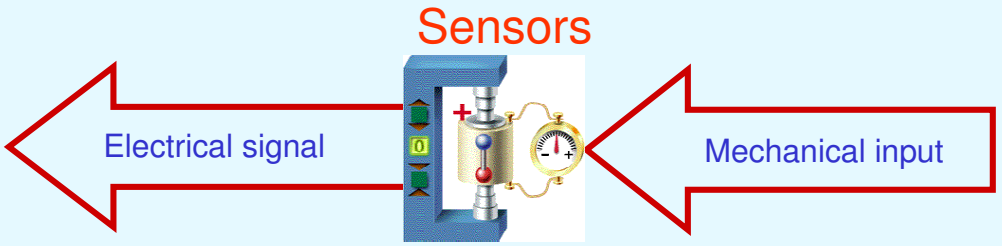
CENTRO RICERCHE FIAT

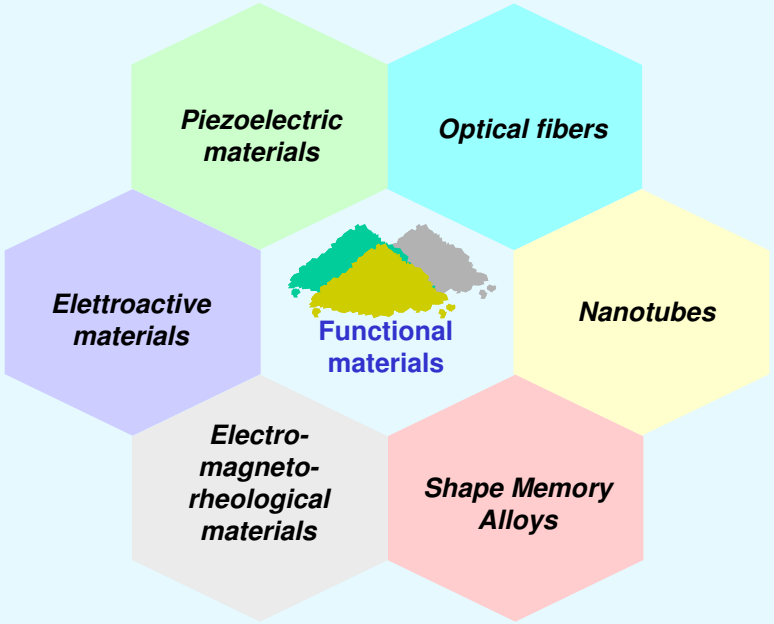
Smart materials: the enable technology

Smart materials are able to modify their functional characteristics if stimulated with electrical or magnetic fields, temperature, light, etc…

They can substitute dozens of discrete actuators and sensors now present in a vehicle. This permits to **simplify components and then to reduce size, weights and costs**







Main advantages respect to traditional components:

- *Act simultaneously as sensors and actuators*
- *Perform controlled mechanical action without any external mechanisms*
- *Are adaptive with the environmental conditions*
- *High level of miniaturisation*
- *New functions development*

CENTRO RICERCHE FIAT

Material focused design

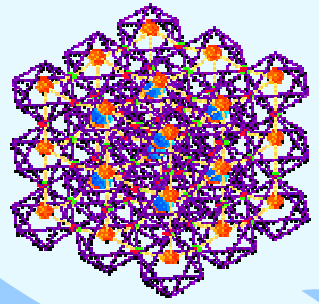
The next challenge in the near future will be to use active characteristics of the materials

SMART MATERIALS WILL PERFORM DIRECTLY THE REQUESTED FUNCTIONS WITHOUT ANY ADDED MECHANICAL PARTS

To obtain the maximum advantage from the application of smart materials as automotive components, a new system-level design approach is needed starting from:

- **Smart materials development and functionalization**
- **Design materials at molecular level to control functional characteristics**
- **New multimaterial integration processes**
- **Active structures development**

From Component Engineering..

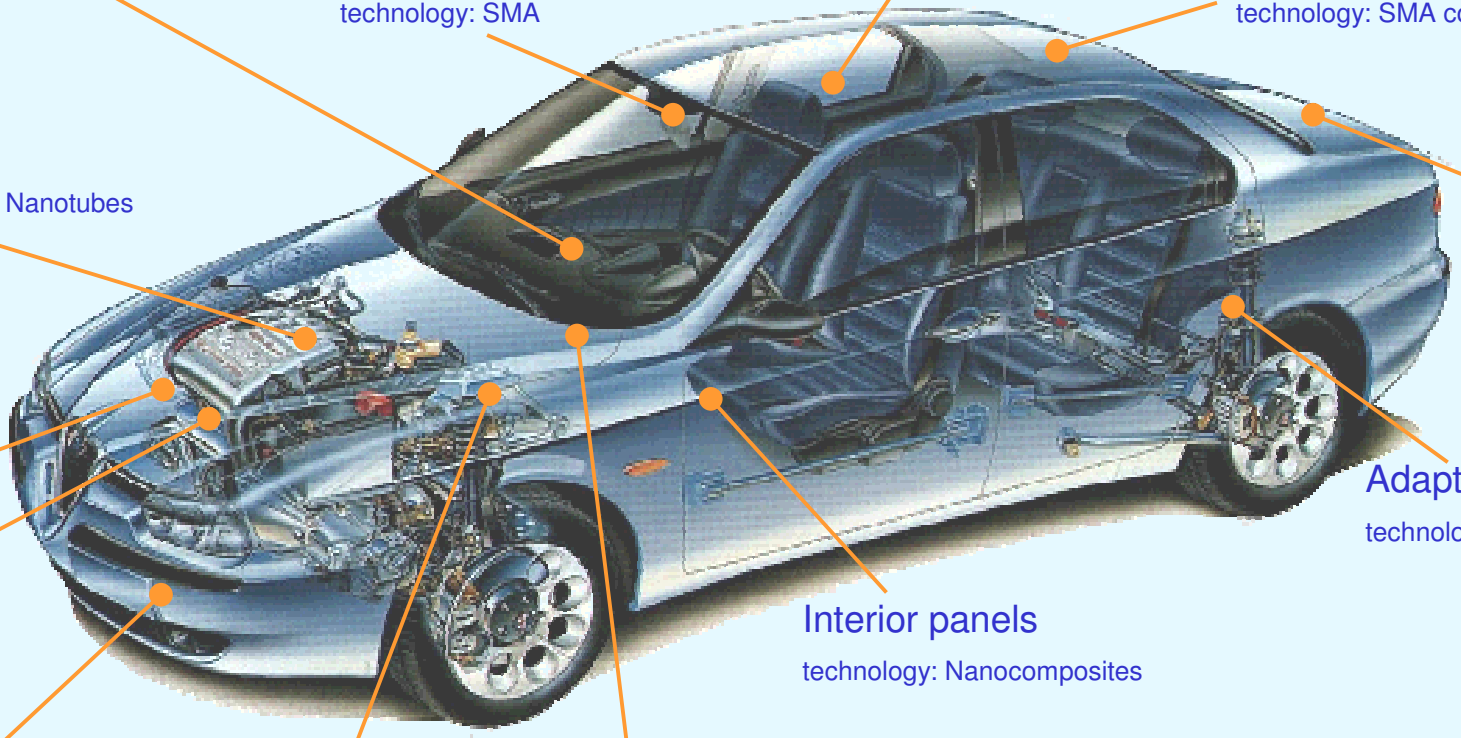


...through MATERIAL DESIGN...

...to Functions Engineering

CENTRO RICERCHE FIAT

Smart materials & multifunctional composites in automotive applications



Active noise and vibration control

technology: Piezo, MR fluids, Functional nanocomposites

Climate control

technology: SMA, micro-fluidic

Mirrors

technology: SMA

Adaptive aerodynamics

technology: SMA composites

Gas sensors

technology: Piezo & Nanotubes

Latches

technology: SMA, piezo

Fuel tanks and lines

technology: SMA

Adaptive dampers

technology: MR fluids

Battery cut-off

technology: SMA

Interior panels

technology: Nanocomposites

Multifunctional bumper

technology: Piezo, Nanocomposites

Dashboard actuators

technology: SMA,piezo

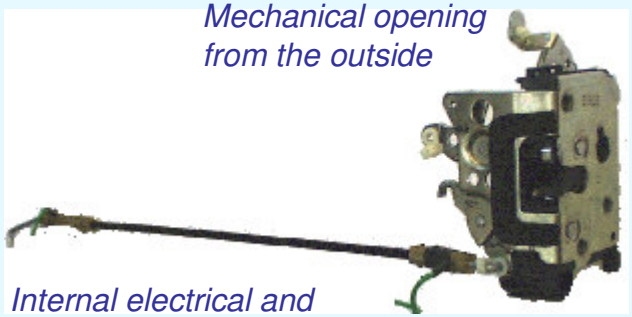
Structural parts

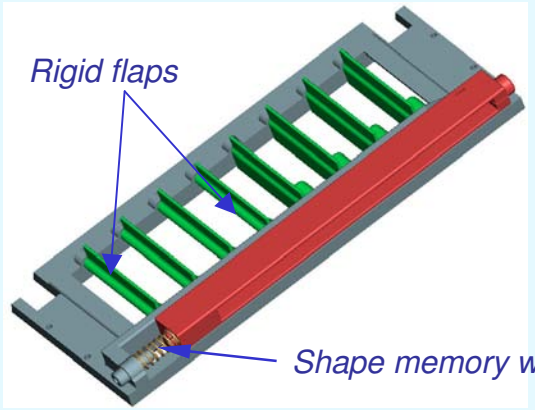
technology: Nanocomposites

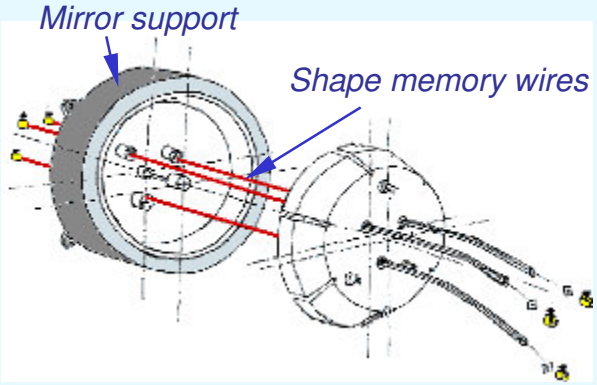
CENTRO RICERCHE FIAT

Shape Memory Actuators for vehicle: CRF developments

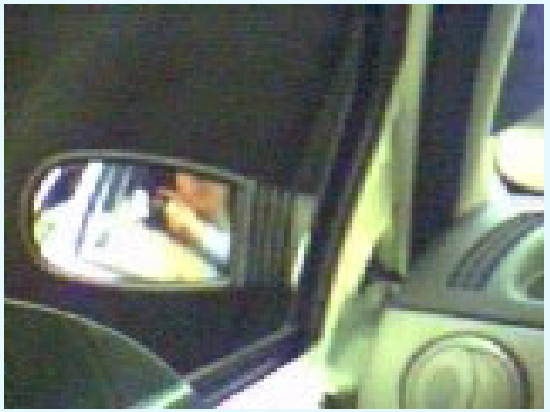
From concept design…







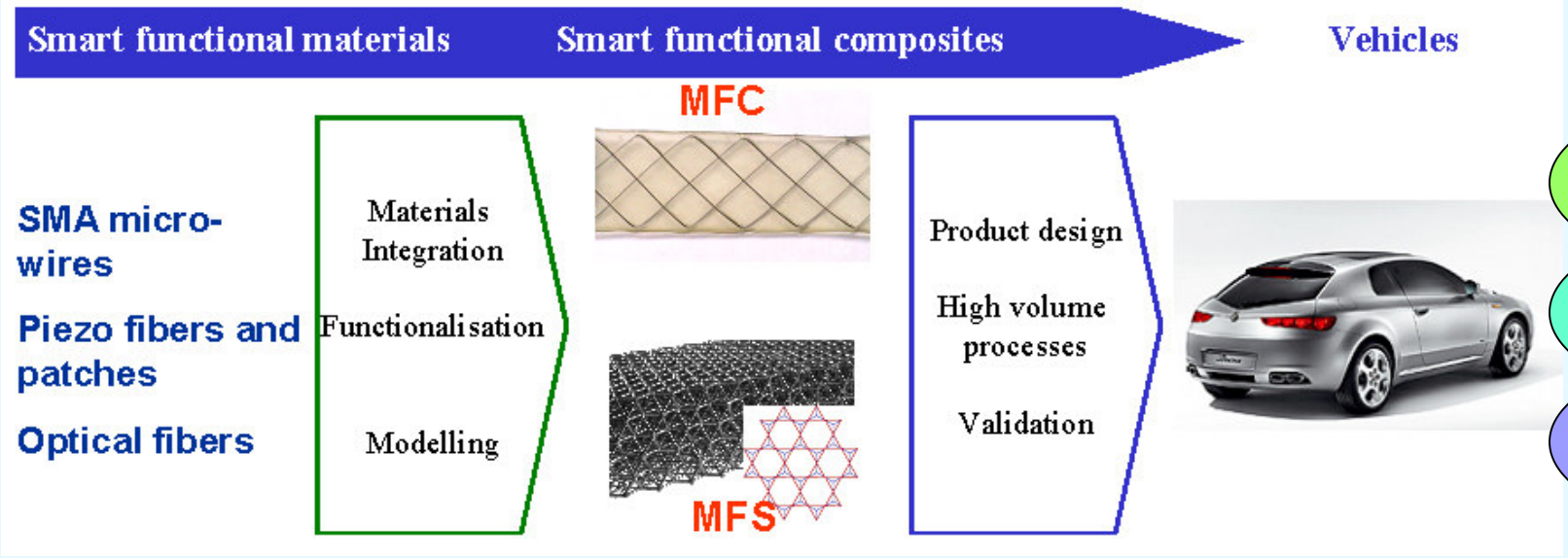
…To prototypes:



CENTRO RICERCHE FIAT

Multifunctional composites: a new design philosophy for innovative functions

Smart materials allow a new design concept of actuation systems from a "one-to-one" replacement to embedded active fibers in functional composite passing through integration of SM element in mechanical structures

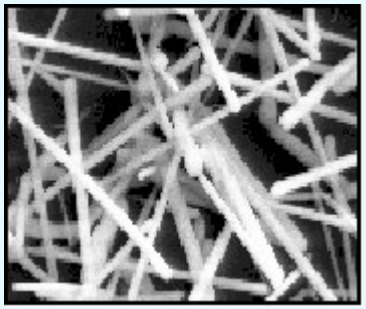


CENTRO RICERCHE FIAT

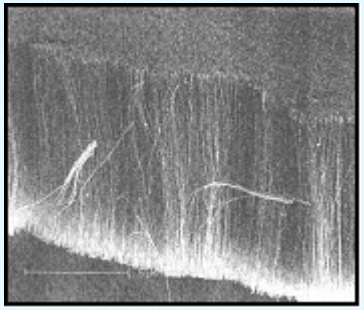
Multifunctional composites classification

MULTIFUNCTIONAL COMPOSITES

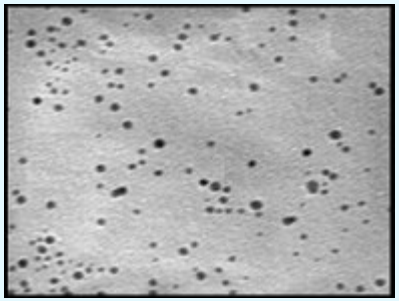
SMA / Piezo-materials based multi-functional composites



Carbon Nanotubes based nanocomposites



Metal Nanoparticles Magnetic nanocomposites

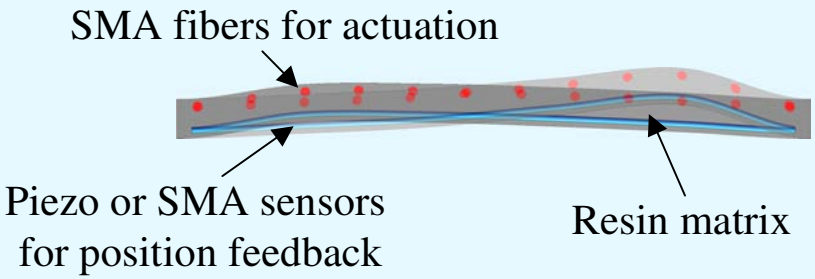


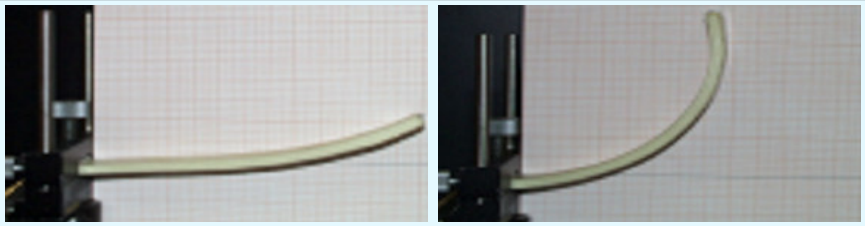
Goal

Production of NEW ADVANCED COMPOSITE MATERIALS for the realization of parts and components in new generation vehicles

CENTRO RICERCHE FIAT

Multifunctional composites for adaptive aerodynamic





Active flaps based on SMA composite

Multifunctional composite structure

Active material with integrated fibers	→	**Surface morphing and stiffness adaptation**
Distributed deformable sensor layer	→	**Detection of deformation feedback**
Smart composite structure	→	**Adaptive noise reduction**

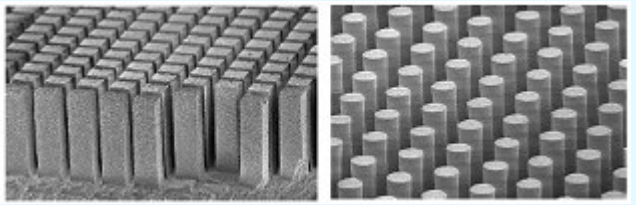
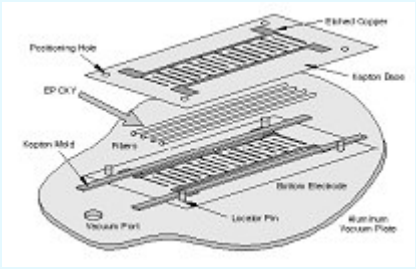
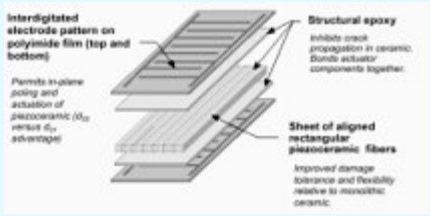
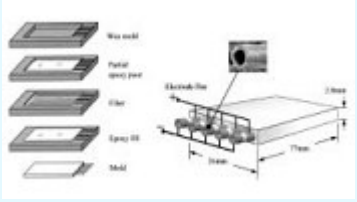
Integration of multifunctional composite in a roof module:

- **Aerodynamic control based on vehicle's speed and dynamic**
- **Noise active control**
- **Rear turbulence control**

CENTRO RICERCHE FIAT

Piezoelectric composites

Active piezoceramic fibrous phase embedded in a polymeric matrix phase – State of the Art

Composites	Smart Material Corp.	Piezoelectric rods embedded in a polymer matrix and aligned through the thickness of the device	Ultrasonic and acoustic transducers	
Active Fiber Composite (AFC)	MIT	Uniaxially aligned piezoceramic fibers surrounded by a polymer matrix. The interdigitated electrodes deliver the electric field required to activate the piezoelectric effect in the fibers.	Structural actuation	
Macro Fiber Composites (MFC)	NASA Langley Research Center	Sheet of aligned rectangular piezoceramic fibers with Interdigitated electrode pattern on polyimide film	Structural actuation	
MFCX Active composites	University of Michigan	Hollow cross-section fibers	Means of lowering the typically high voltages required to actuate AFC's and MFC's	

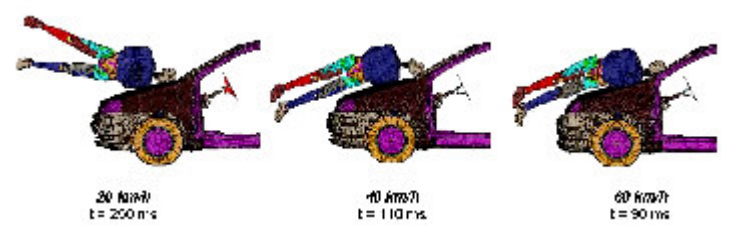
Advantages respect to bulk piezo-materials…

- ✓ **Fibers are protected by the polymer matrix**
- ✓ **Easily conforming to curved surfaces**
- ✓ **Both bending moments and twisting torques available**
- ✓ **Higher displacements**

CENTRO RICERCHE FIAT

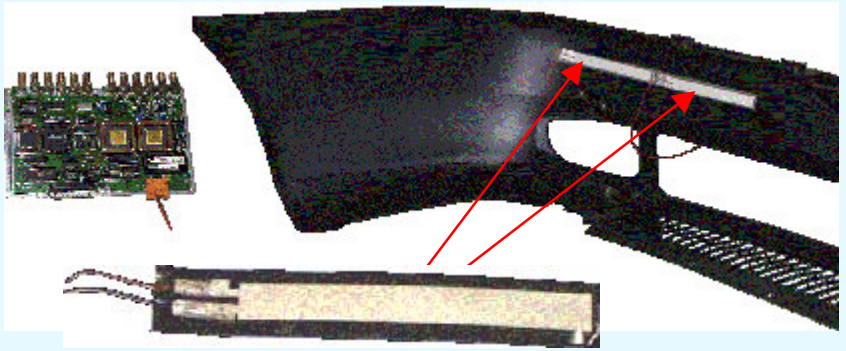
Bumper for pedestrian impact recognition

A new European regulation for pedestrian protection in head to hood impact asks automotive producers to use new active pedestrian protection systems

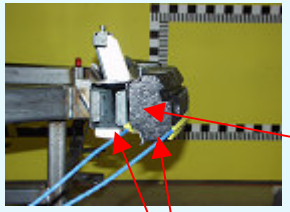


Head-to-hood impact time for an adult pedestrian

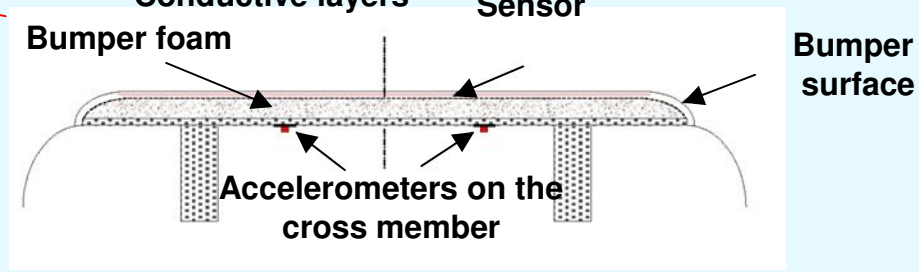
Sensory system to detect impact and recognize impacting object becomes necessary in cases where passive protection isn't enough



Piezo modular thin sensors embedded in the bumper with custom electronic unit for signal analysis and pedestrian detection algorithms – CRF solution



Fiber Optic
or piezo polymer coaxial cable



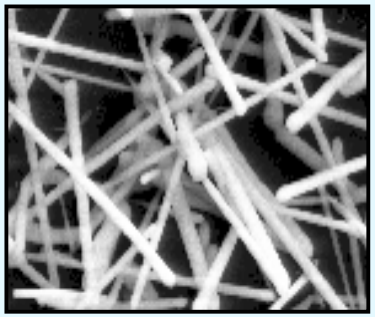
Available solution based on "add-on" approach

CENTRO RICERCHE FIAT

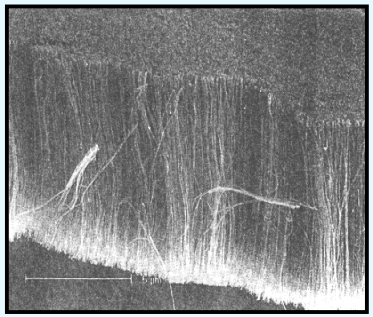
Functional composites classification

FUNCTIONAL COMPOSITES

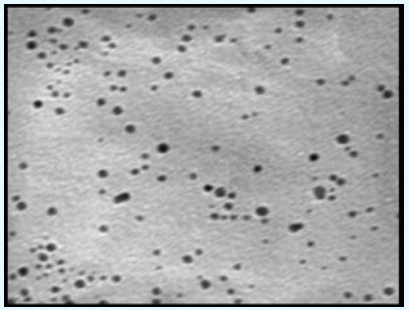
multi-functional composites based on **SMA / Piezo-materials**



Nanocomposites based on **Carbon Nanotubes**



Magnetic nanocomp. based on **Metal nanoparticles**



Goal

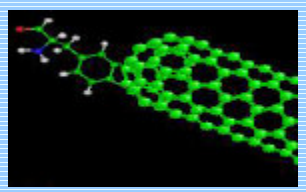
Production of NEW ADVANCED COMPOSITE MATERIALS for the realization of parts and components in new generation vehicles

CENTRO RICERCHE FIAT

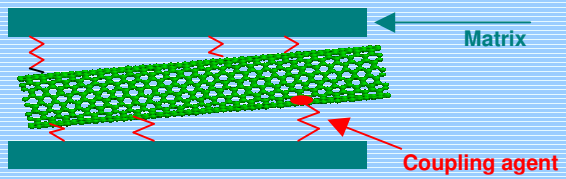
CNT based functional nanocomposites

Nanocomposite materials obtained by integration of functionalized CNT in thermoset or thermoplastic polymers, ceramics or metals

Model of Multi-Wall CNT



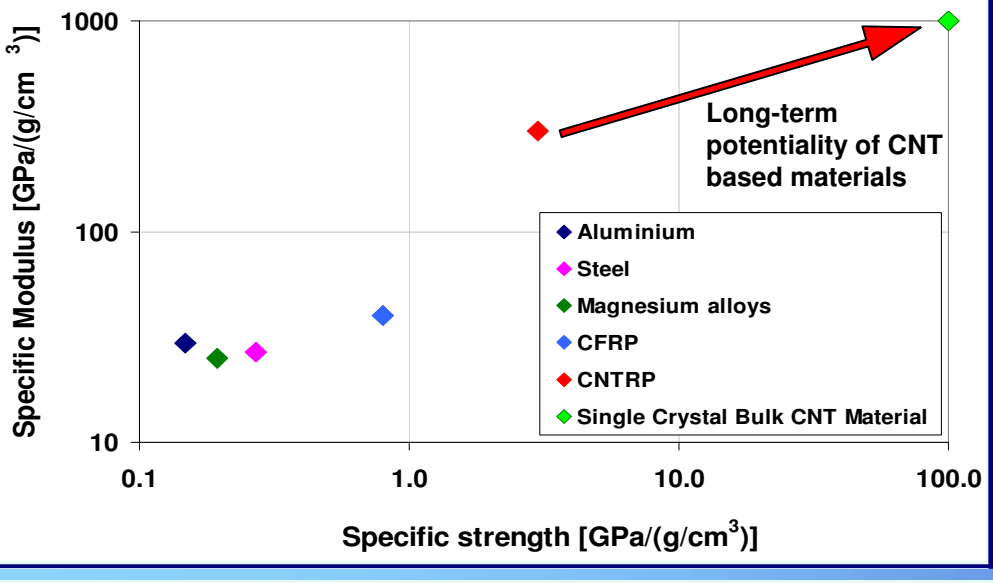
Model of functionalized CNT



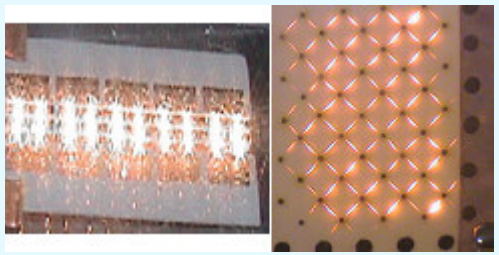
Realization scheme of a CNT based nanocomposite

CNTs have superior mechanical, thermal and electrical properties respect to traditional carbon fibers, so they are the best fillers for the realization of composite materials with structural and functional properties and with high performances

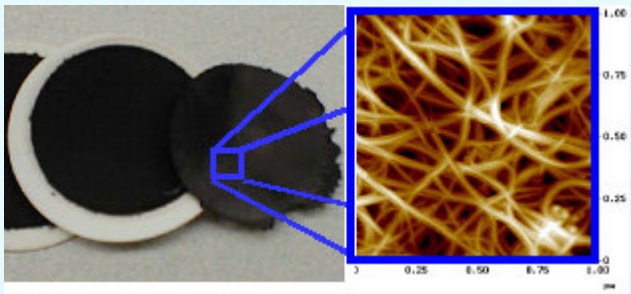
STRUCTURAL APPLICATIONS



FUNCTIONAL APPLICATIONS



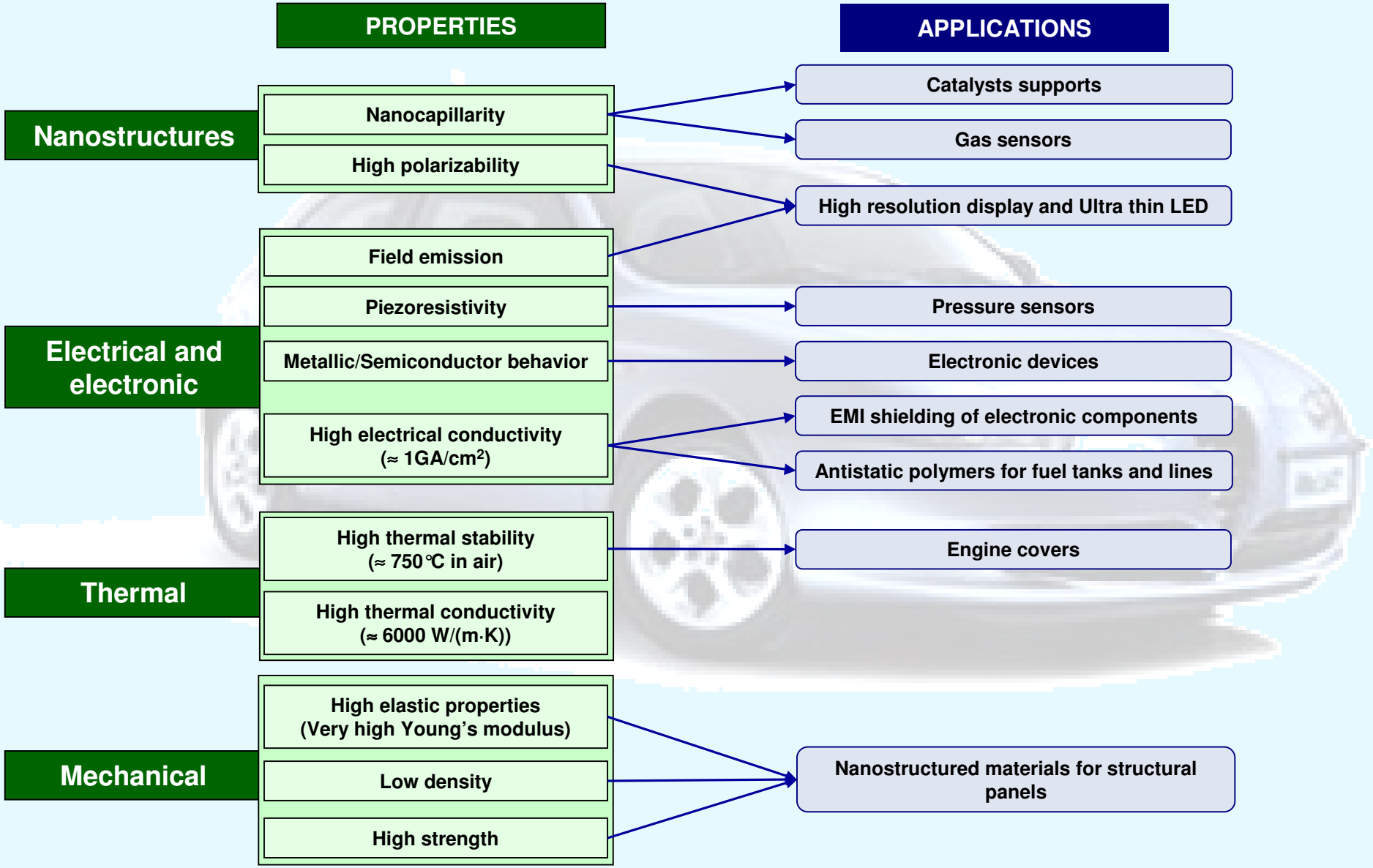
CNT based lighting microbulbs



CNT sheets used as support for catalysts in micro fuel cell or as gas and pressure sensors. In the box, an image of the structure obtained by Atomic Force Microscopy (AFM).

CENTRO RICERCHE FIAT

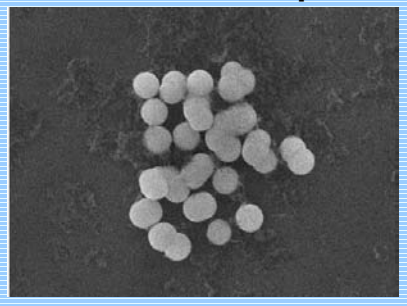
CNT and nanostructured materials: automotive applications



CENTRO RICERCHE FIAT

Magnetic nanocomposites

Magnetic nanocomposites are metal ferromagnetic nanoparticles (Fe, Co, Ni) dispersed in polymeric matrix. These nanocomposite materials permit to join together characteristics of different materials.



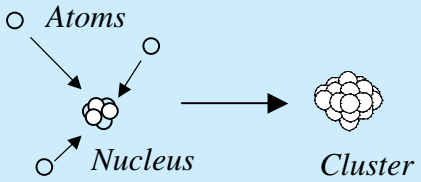
SEM micrograph of Co nanoparticles synthesized by polyol process

TEM micrograph of a Co/Polystyrene nanocomposite

Advantages:

- Magnetic characteristics optimization during composite synthesis
- Flexible and lightweight material
- Low chemical reactivity

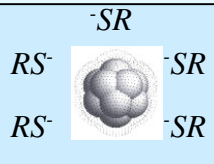
Atomic cluster synthesis (active metal)



"Soft chemistry"

- High chemical purity of achieved products
- The equipment used for this process is simple and then inexpensive
- A wide range of metals can be obtained in nanometric and sub-micrometric form
- The produced powder is **monodispersed and with a regular morphology**

Clusters surface passivation

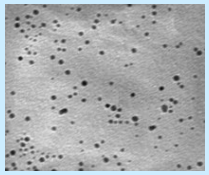


Metallic cluster with an organic shell

Passivation/Compatibilization Process

- **Prevention of particles aggregation, oxidation-contamination**
- The alkylic group (R) work as coupling agent (improvement of interface Me/polymer properties) and as wetting agent (the Me particles are more dispersible in the oligomers before the cross- linking)

Dispersion of passivated clusters in polymers



Continuous matrix:

- Thermoplastic polymers
- Thermosetting polymers
- Elastomers

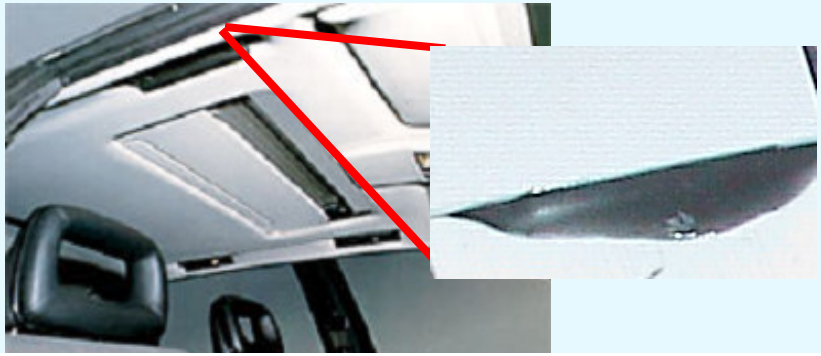
Dispersed phase:

- Fe, Co, Ni clusters
- Bimetallic clusters: alloys, multilayer structures
- Poly-metallic clusters

CENTRO RICERCHE FIAT

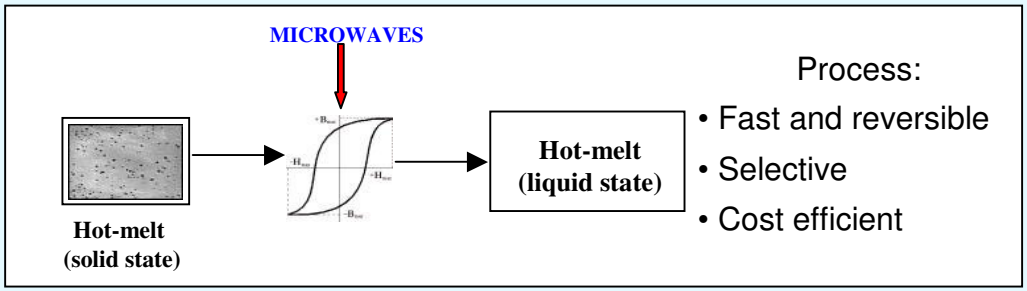
Magnetic nanocomposites applications

Microwave-activatable hot-melt adhesive

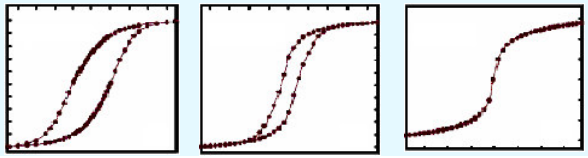


The hot-melt adhesives are binder without solvent. They are solids at temperature below 80°C and they become low viscosity liquids above this temperature value. The hot-melt adhesives set quickly during their cooling.

The innovative approach using magnetic nanocomposites as adhesives …….
…. Microwave to activate hot-melts



Pressure, position and temperature sensor



Hysteretic cycle of a magnetic composite can be designed and optimized by selecting the magnetic nano- particles and changing their morphology

This means to have no hysteretic behavior and than to produce selectively, more precise and high sensible sensors….

- **Intelligent airbags**
- **Rear-mirrors**
- **Seats**

CENTRO RICERCHE FIAT

Conclusions

- In automotive industry, traditional composites materials, in spite of their inherent attribute of lower weight, design flexibility and corrosion resistance, are slow to take off especially for their high costs. Particularly an increase of costs only to reduce the weight of vehicles structures are not sustainable for car makers.

- In the last decades there was a fast growing of functional density in cars. Today a fully equipped car has hundreds of sensors, actuators and electronic parts. In the near future the new paradigm will be: reducing the weight of functions !

- Smart materials have already a great potentiality as miniaturized sensors and actuators in car components, and they will be introduced in car components in the next 2-3 years.

- SM, due to their form factor, are easily embeddable in plastic matrix, forming new multifunctional composites with amazing performances

- Multifunctional composites could integrate functionality and costs, then they could be introduced in cars as a substitution of heavy, complex and expensive discrete electromechanical components

- Multifunctional composites need for new efforts in terms of modelling, design, control and materials integration. A new multi-disciplinary approach is needed. CRFiat is deeply involved in this field