Centro di Progettazione, Design & Tecnologie dei Materiali

Materials and Structures Engineering DEPARTMENT

Technologies and Processes AREA

Laboratory of Materials Technologies

SMART materials

Multifunctional composite materials

Rocco Rametta

Presentation Out line

- CETMA: an overview
- Introduction to “SMART”
- Examples and applications
    - SMART impact and damage resistance
    - SMART vibration damping
    - SMART sensing
    - SMART actuation
- Conclusion

CETMA: an overview

CETMA – Centro di Progettazione, Design & Tecnologie dei Materiali

CETMA is a consortium of public research agencies and private industrial companies.

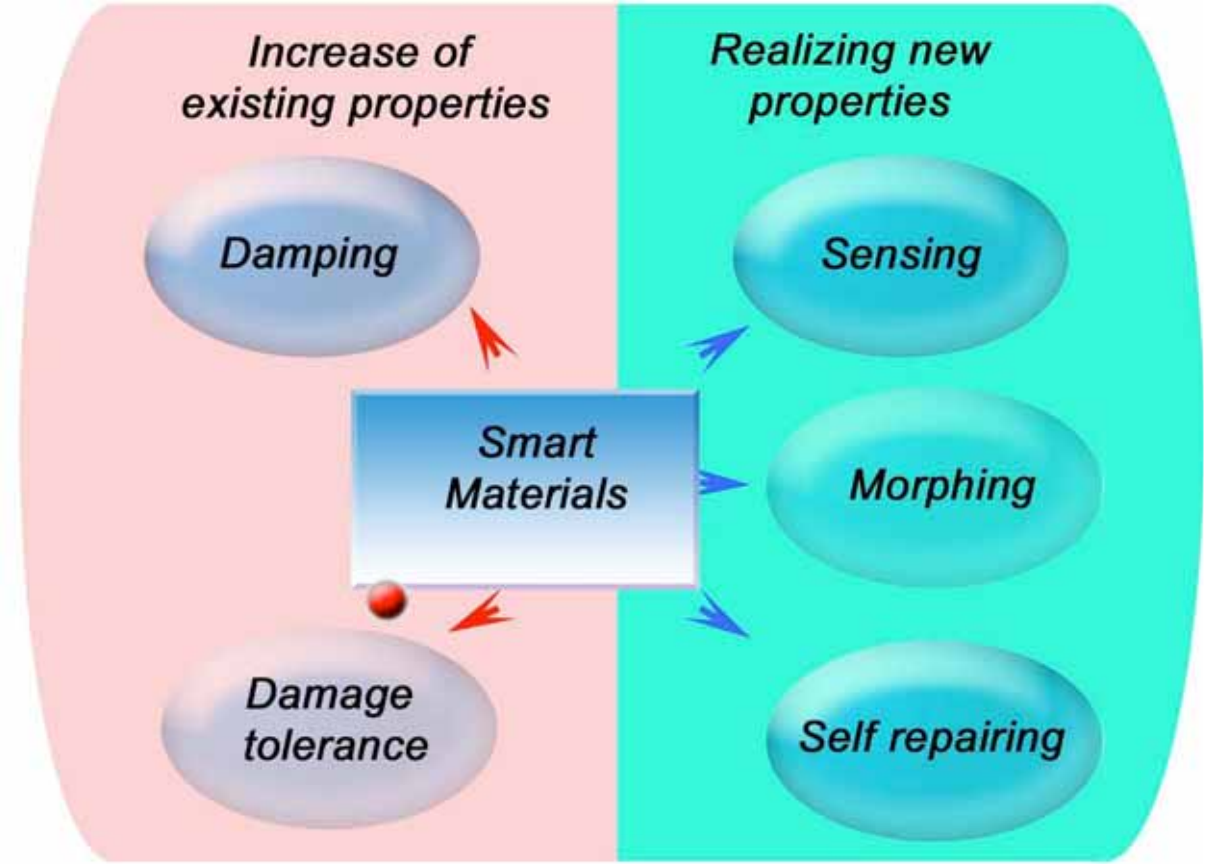
It carries out **applied research** activities on **materials**, **processes** and **methodologies** towards the development of innovative products for industry and services sectors.

Within the Departments of Materials and Structures Engineering, some specific research and innovation activities on SMART Materials are in progress.

Experimental tests are performed thanks to the Laboratory of Materials Technologies.

Introduction

The demand on new materials for engineering applications, where the need of high performances is accompanied by the request of limited weights, implies the development of innovative "smart", "multifunctional", and "adaptive" materials.



SMART

Self Monitoring
Analysis Reporting
Technology

Very important!

Often these new properties can change depending on external stimuli

Introduction

Among the "smart" materials, the most common are:

• **Piezoelectric materials** produce a voltage when stress is applied, and this effect can also by applied in the reverse manner (a voltage produces stress).

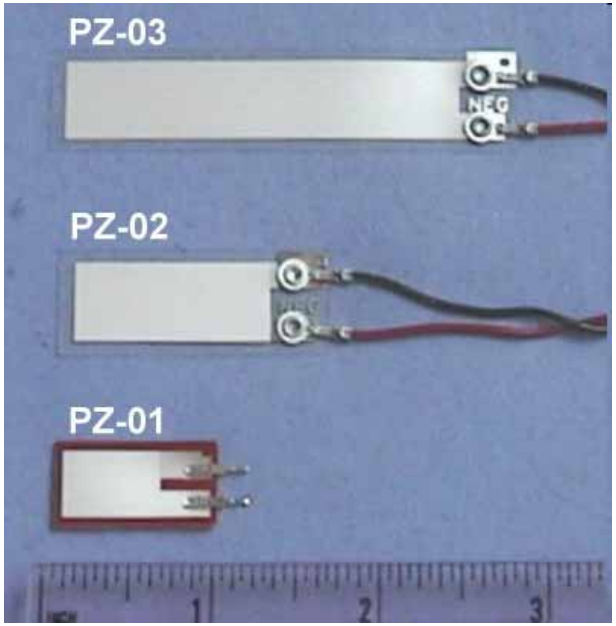
• **Shape memory alloys** are thermoresponsive materials where deformation can be induced and recovered through temperature changes.

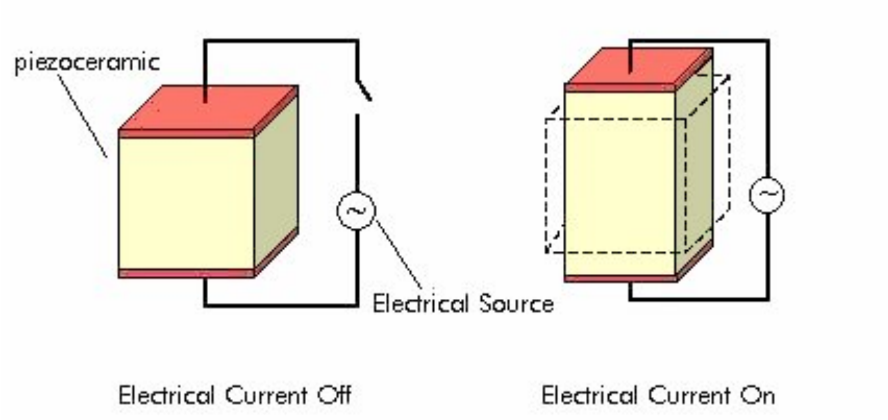
• **FBG sensors** are strain sensitive materials where induced deformations result in variation of signal wavelength.

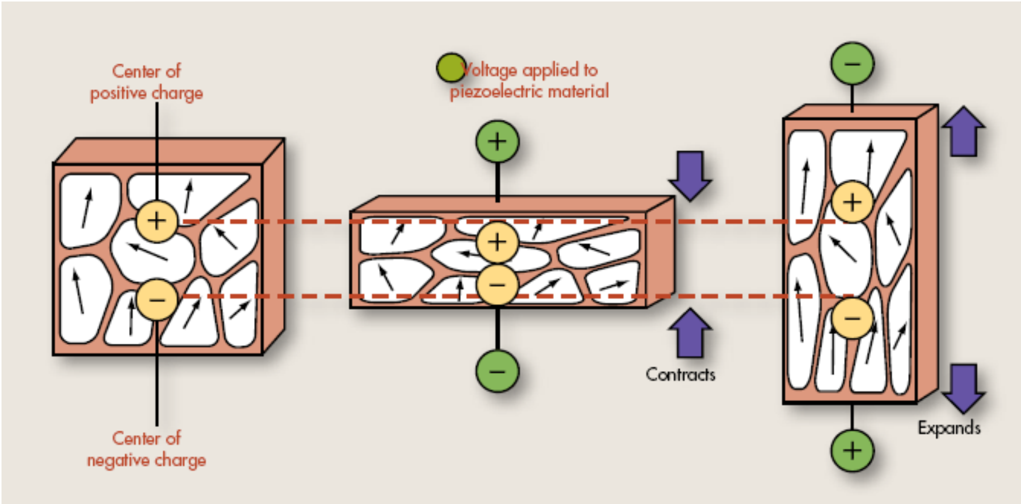
The main reasons of the success for these materials are their high specific properties and the possibility to shape them as very thin wires and laminas.
Other "smart" materials that are currently studied are: **magnetic shape memory** (alloys that change their shape if an external magnetic field is applied), **pH-sensitive polymers** (materials which swell/collapse when the ph changes), **temperature responsive polymers**, etc.

Introduction

Piezoelectric materials



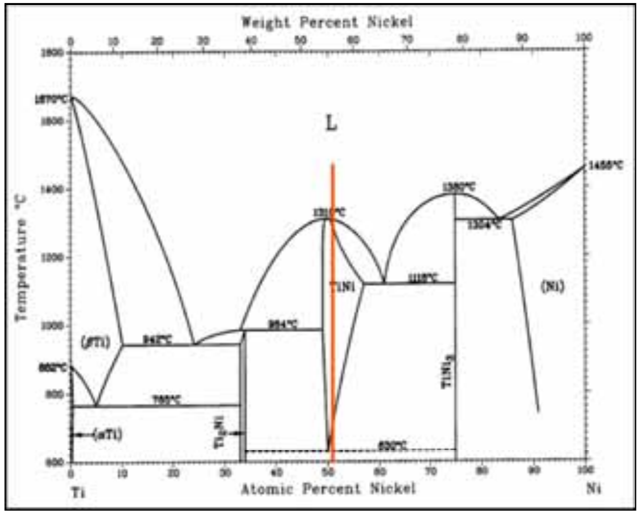


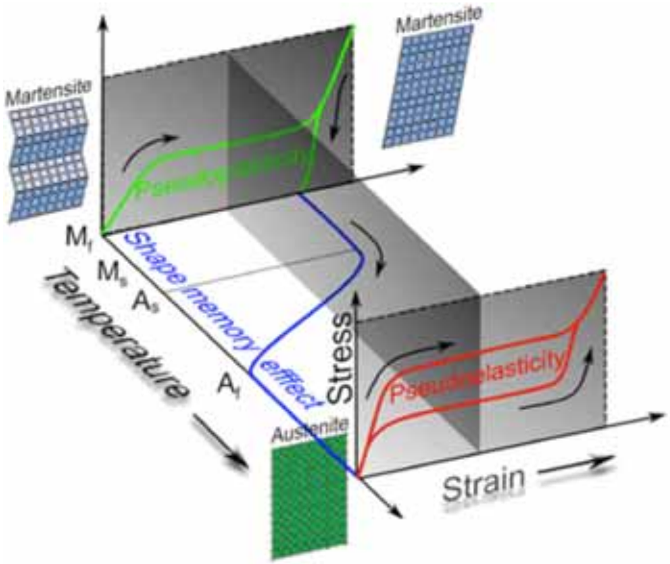


1. The piezoelectric effect causes crystal materials like quartz to generate an electric charge when the crystal material is compressed, twisted, or pulled. The reverse also is true, as the crystal material compresses or expands when an electric voltage is applied.

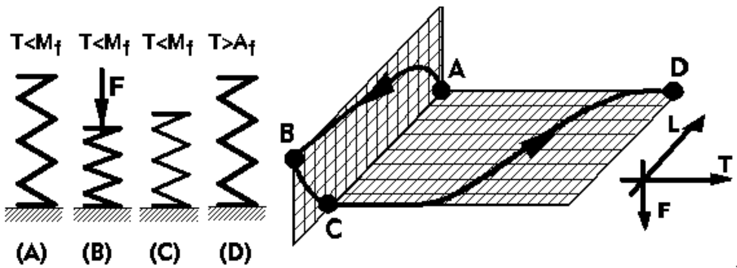
Introduction

Superelastic Shape Memory Alloys (SMAs)

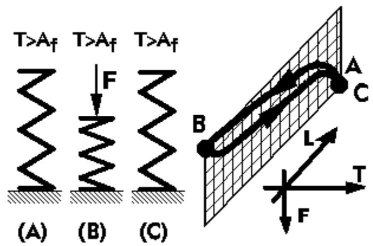




[Free recovery]: the sample is deformed (A to B) and unloaded (B to C) at a temperature below Mf; the residual deformation is restored by heating above Af

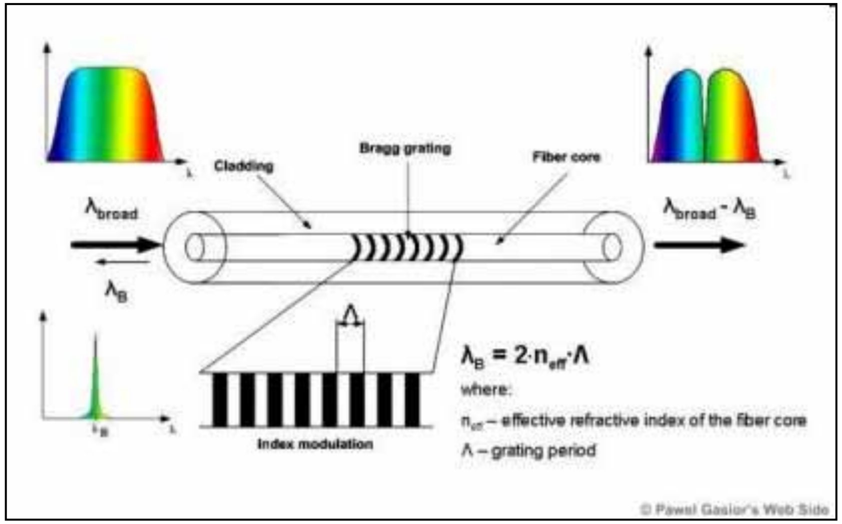


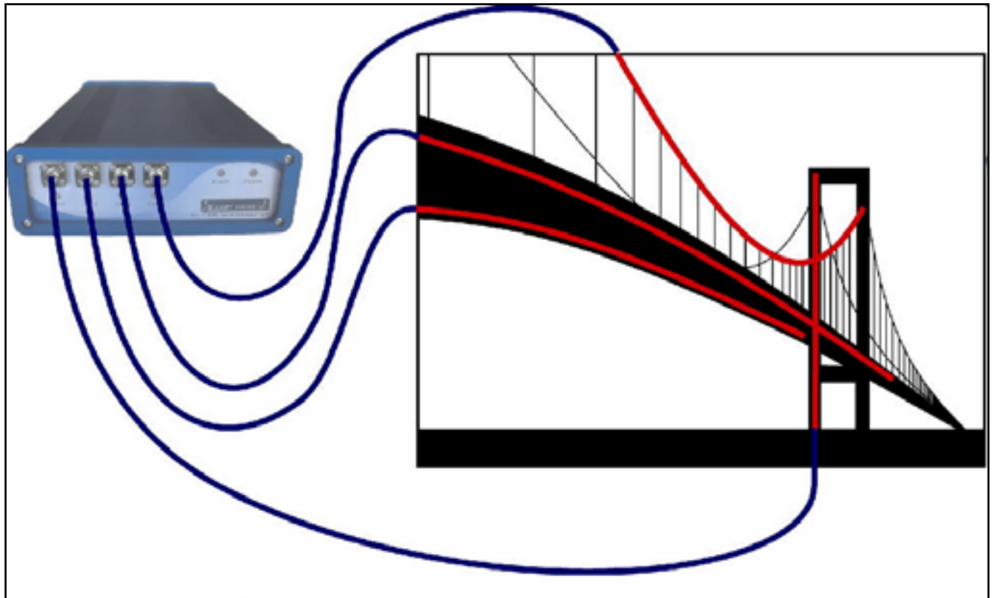
[The superelastic effect]: the sample is deformed at relatively low stresses (A to B) at a temperature above A; During subsequent unloading a complete shape recovery occurs (B to C)



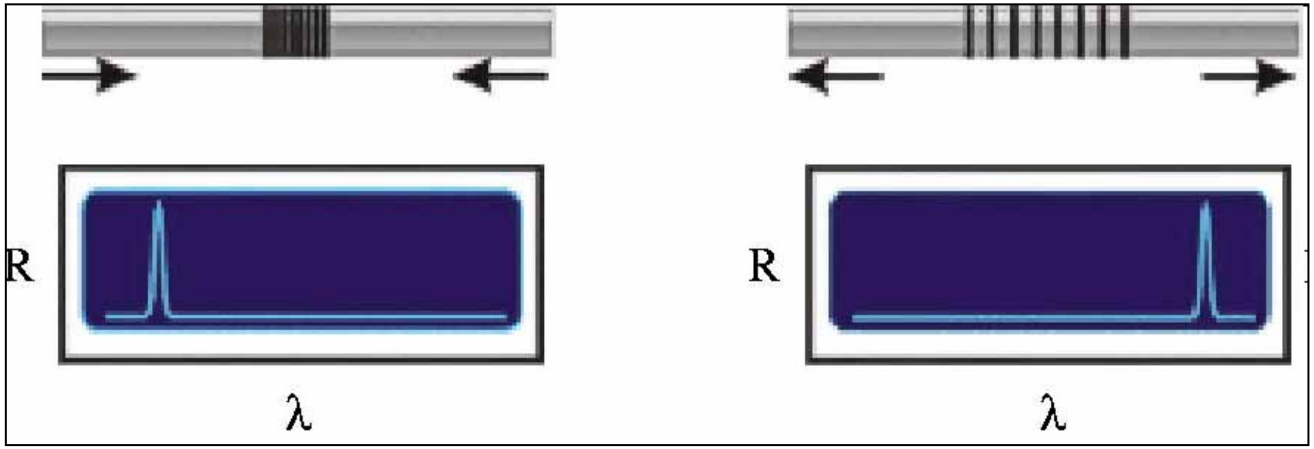
Introduction

Optic fibre sensors

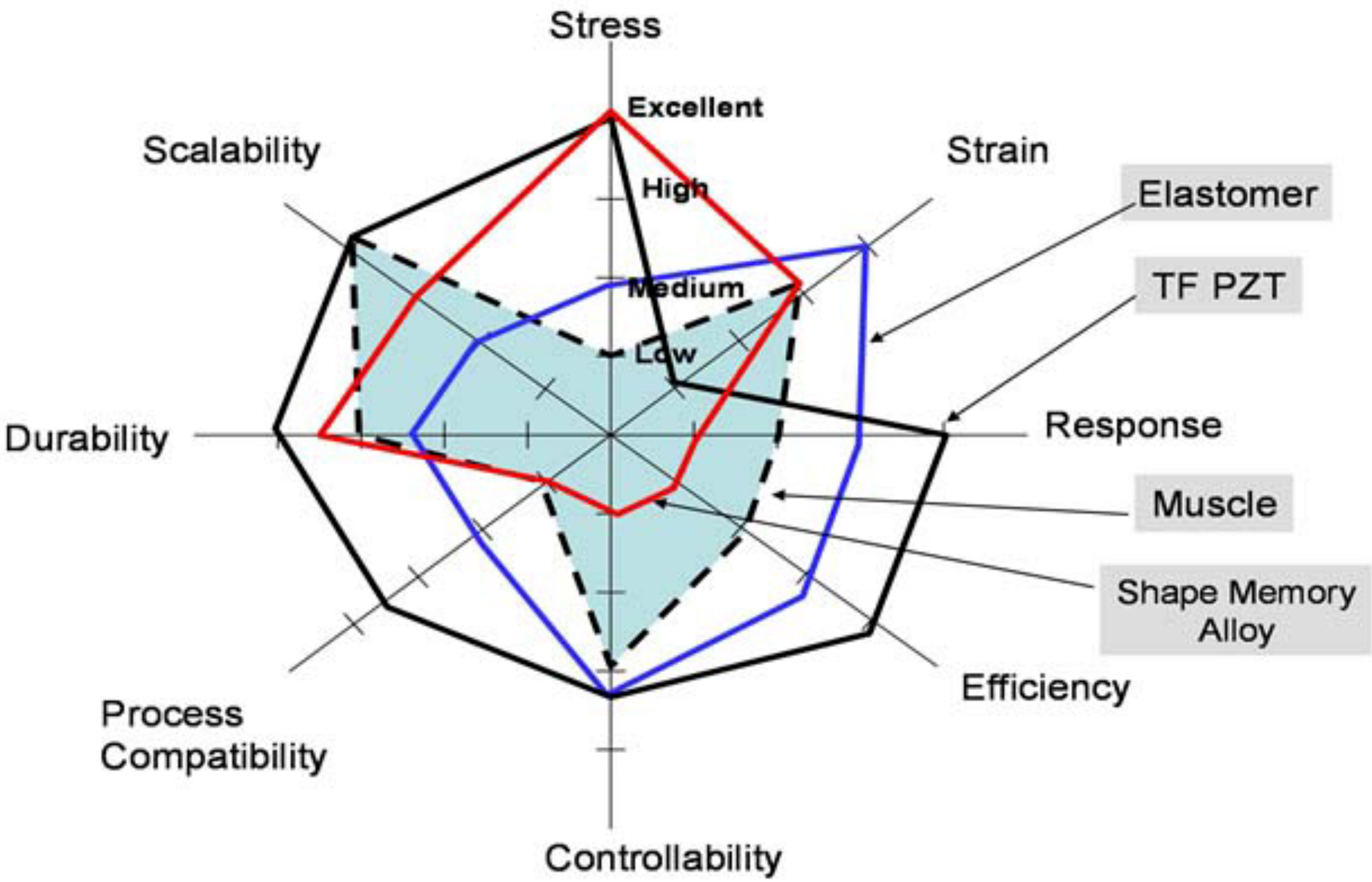




Source: Smart Fibres

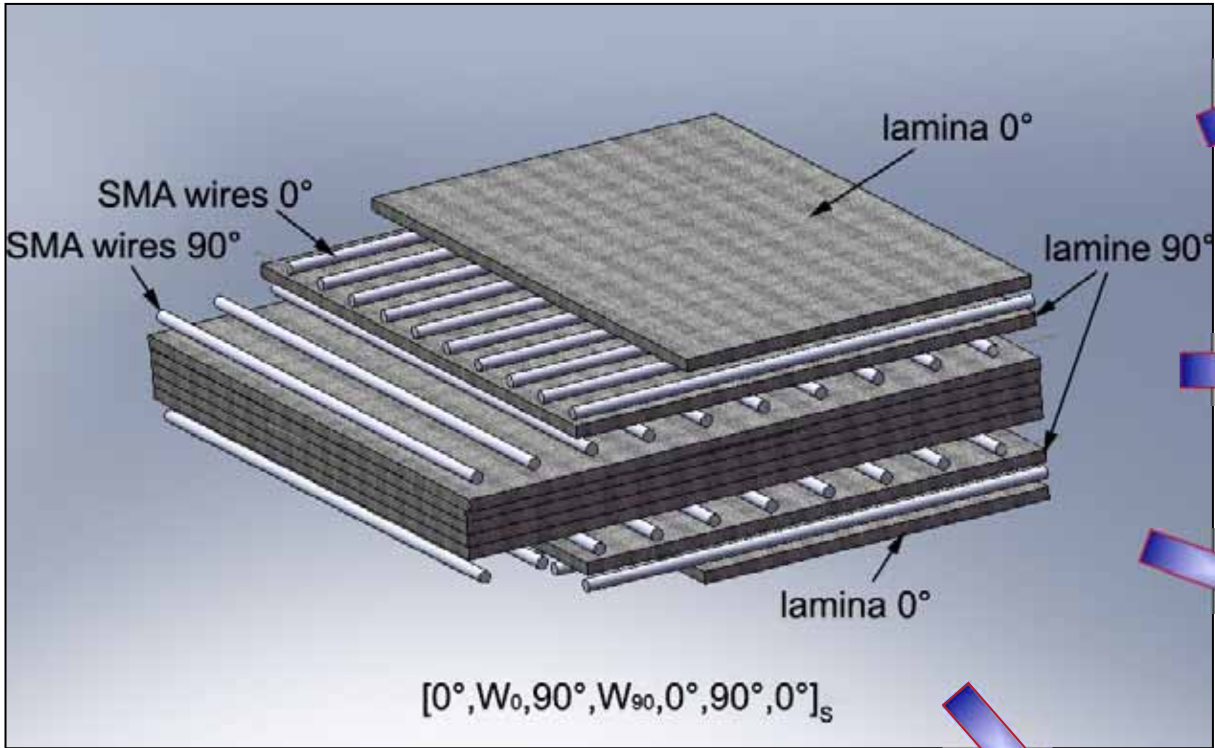


Comparison between piezoelectric (PZT) and shape memory alloy (SMA) materials.



Introduction

SMART composites are generally obtained by integrating materials with actuating and sensing properties, or with high specific mechanical properties.



Increase of damage tolerance

Increase of damping properties

Obtaining Composite actuators

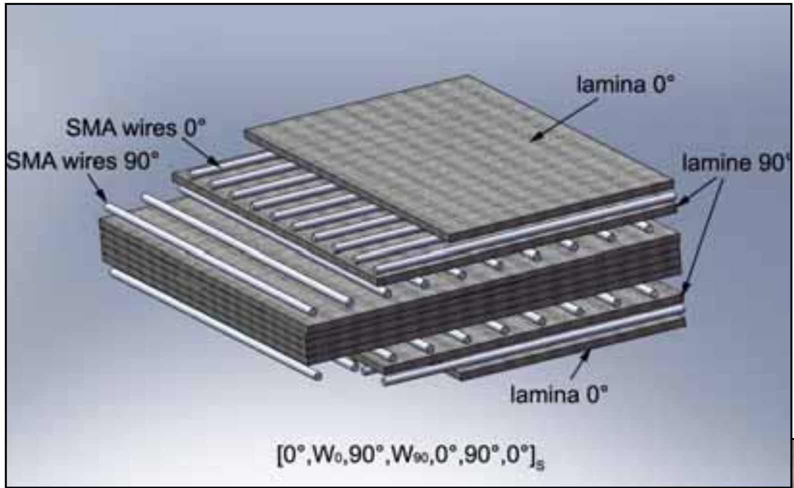
Obtaining Composite sensors

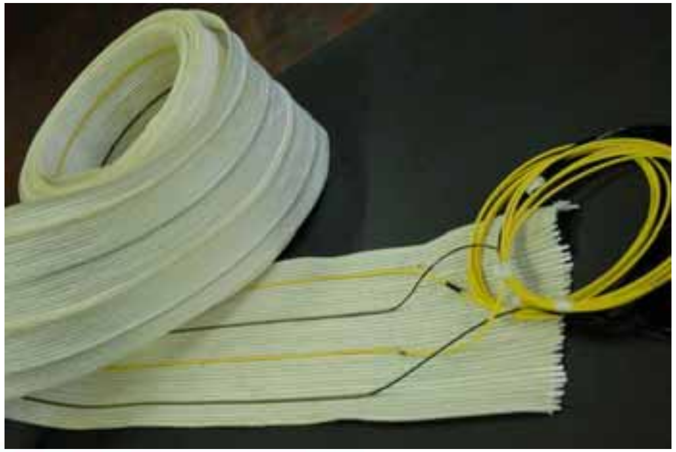
Introduction

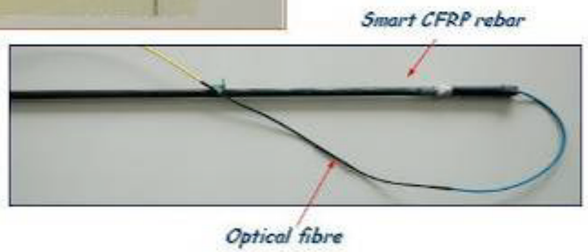
SMART Composite Materials and Components

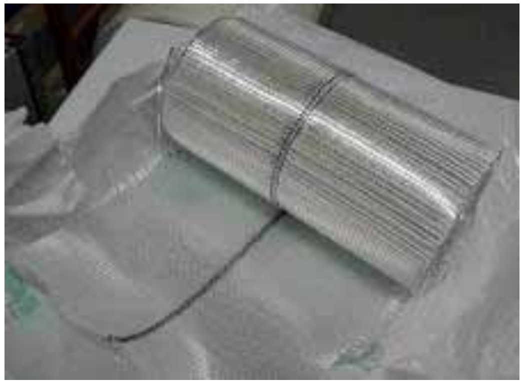
The **main issues** are related to the integration in terms of :

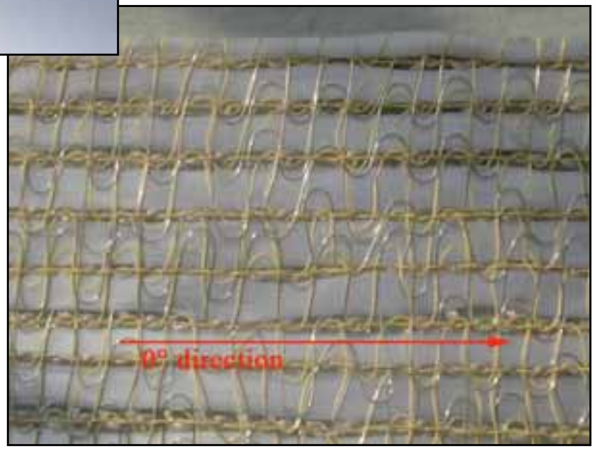
-Embedding











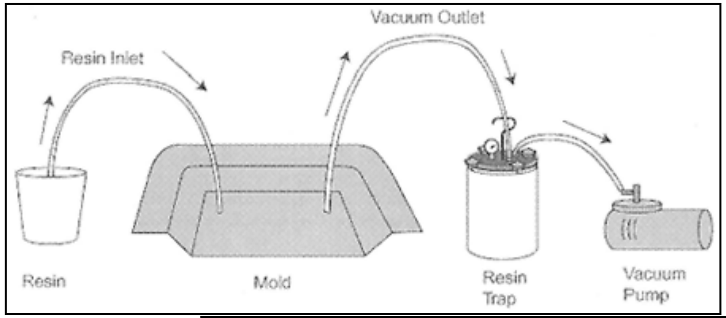
Introduction

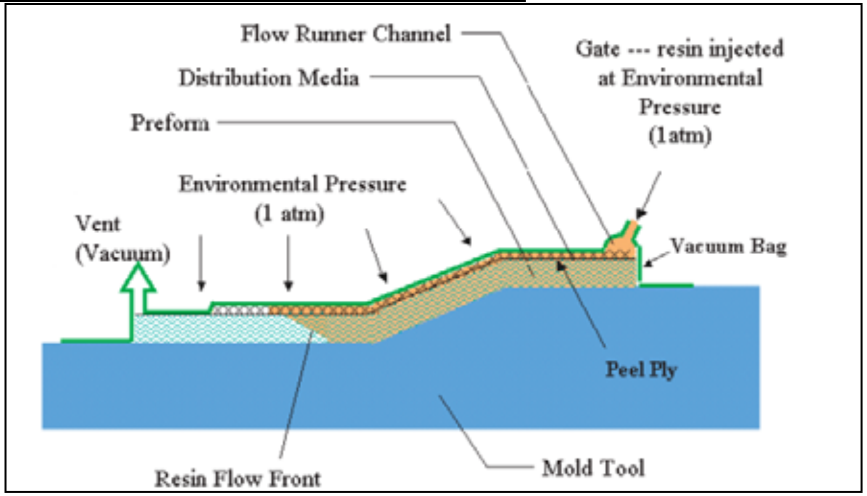
SMART Composite Materials and Components

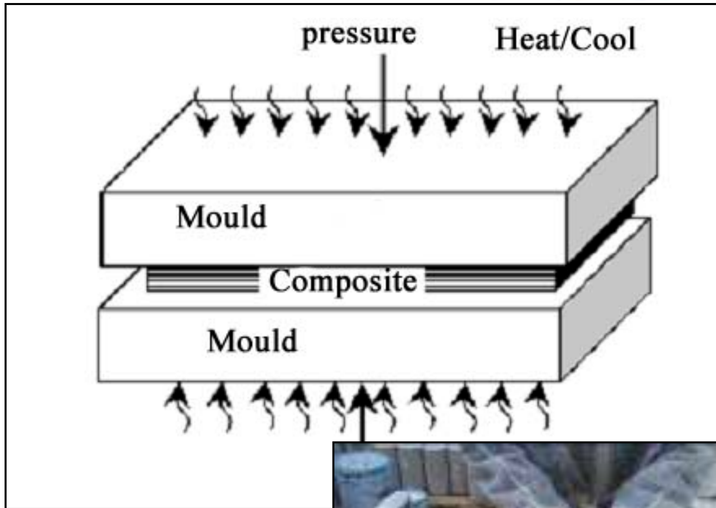
The **main issues** are related to the integration in terms of :

-Embedding

-Forming technologies compliant with the new materials







Introduction

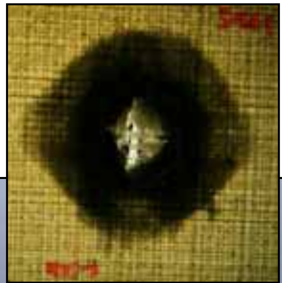
SMART Composite Materials and Components

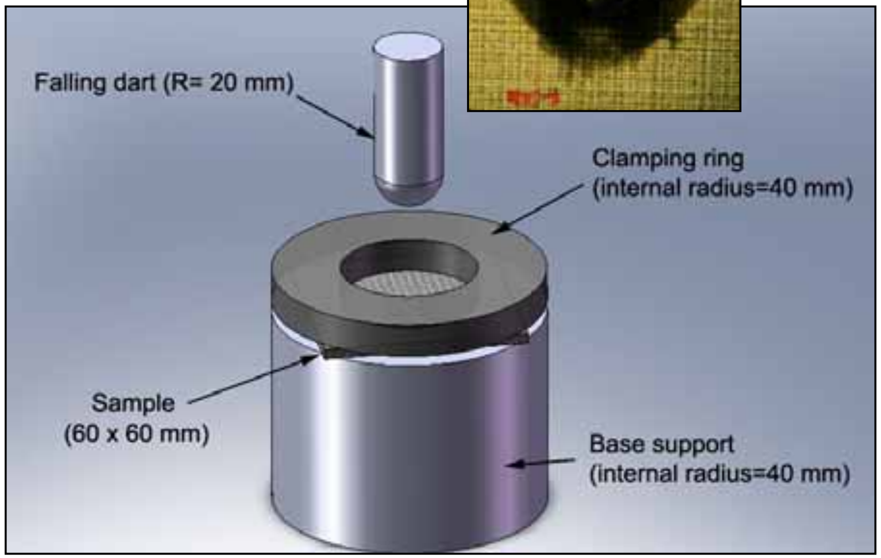
The **main issues** are related to the integration in terms of :

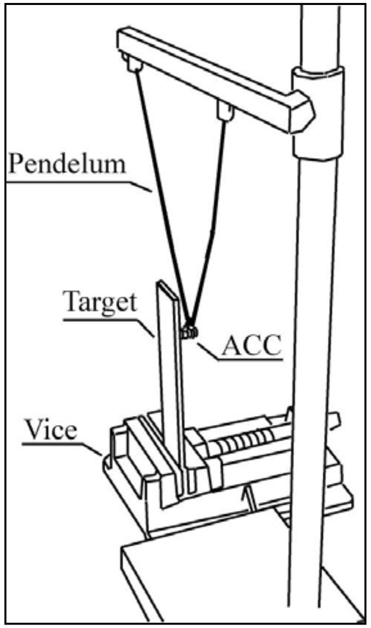
-Embedding

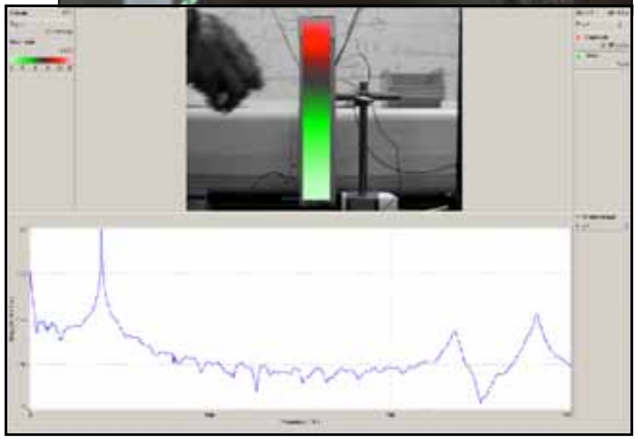
-Forming technologies compliant with the new materials

-Experimental verification of performances









Introduction

SMART Composite Materials and Components

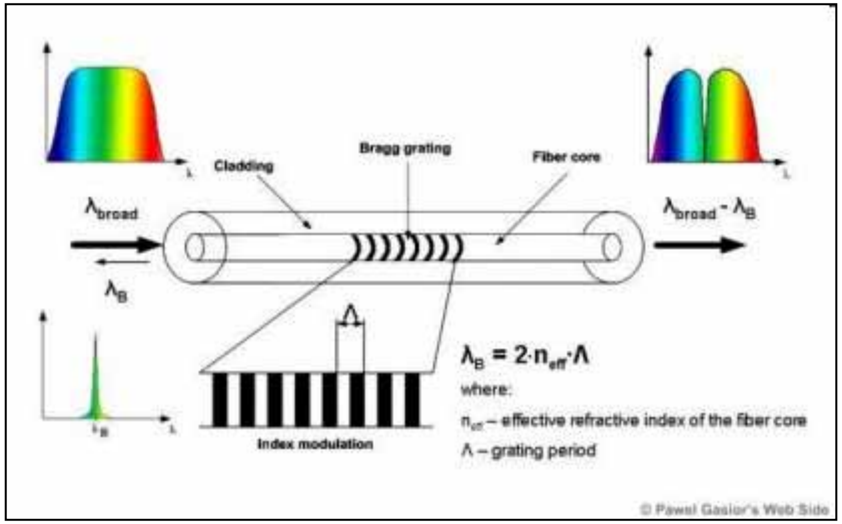
The **main issues** are related to the integration in terms of :

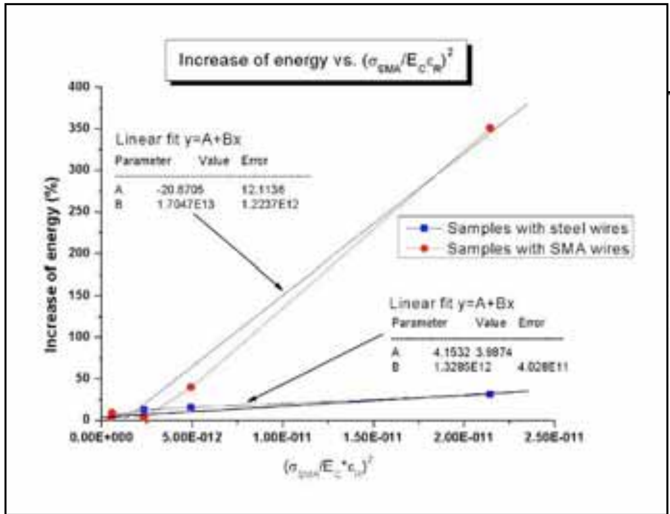
-Embedding

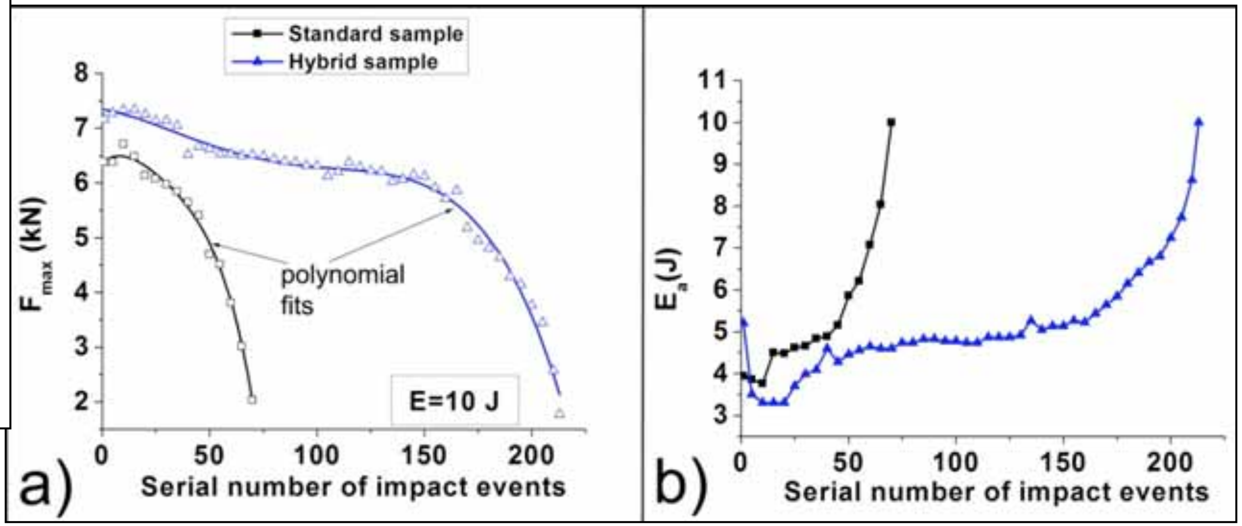
-Forming technologies compliant with the new materials

-Experimental verification of performances

-Design and prediction of performances and functionalities







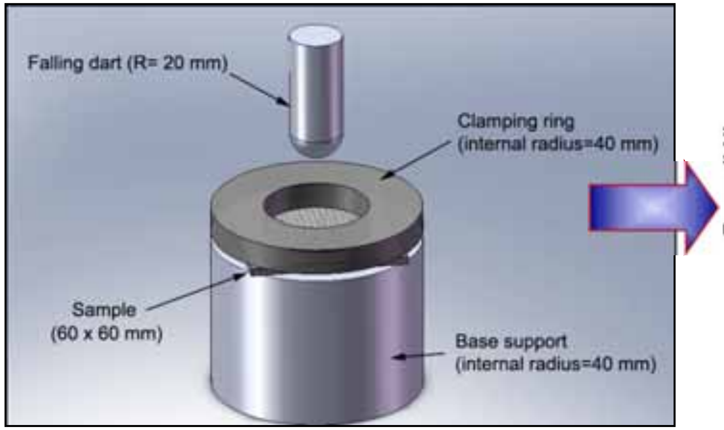
SMART composites with higher damage tolerance

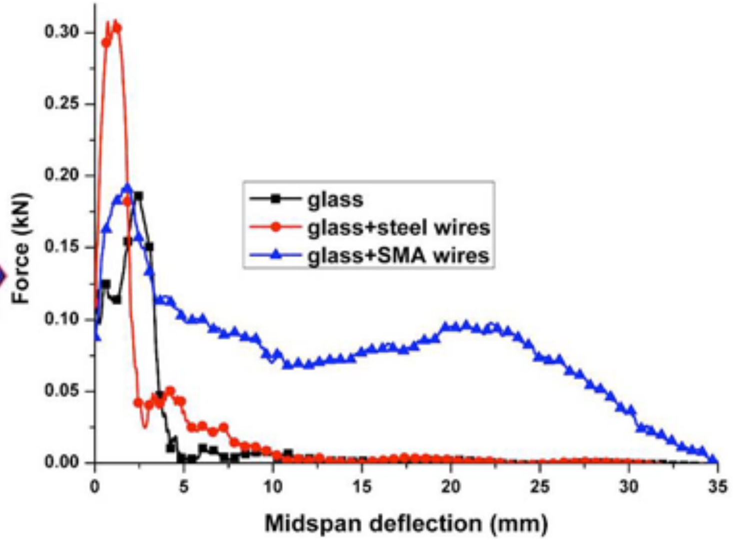
Hybrid composite laminates with higher damage tolerance

-Design

-Production

-Testing





The influence of SMA hybridization was studied by analyzing the change of the Force-time curve during “Falling Dart” Impact test, and by using non-destructive technique for damage inspection (Visual Inspection, thermography, shearometry, etc).

SMART composites with higher damage tolerance

Experimental activities for high impact absorbing materials:

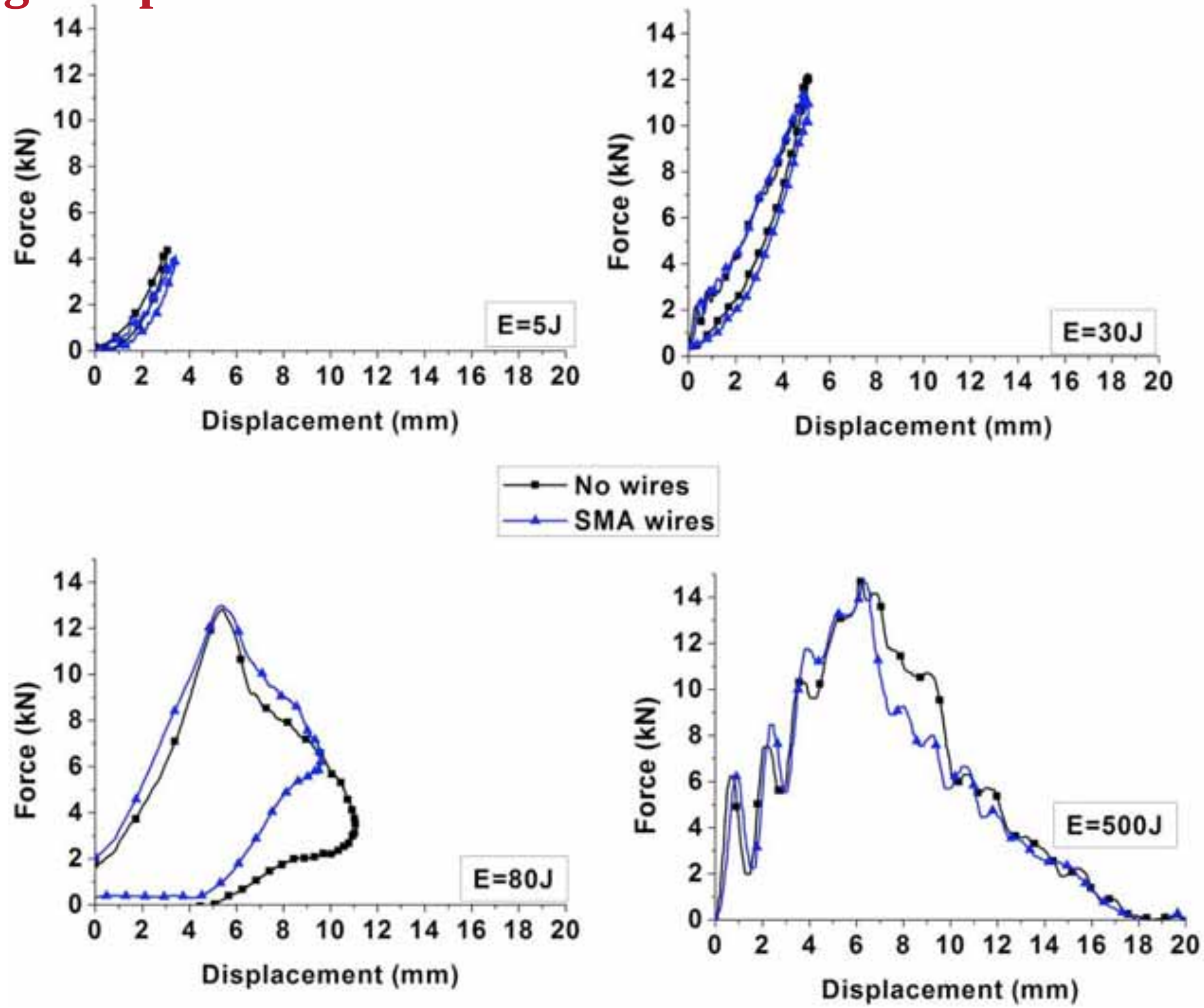
Several laminates have been produced varying:

- **Reinforcing fibres (carbon and glass fibres, woven or multiaxial fabrics)**
- **Type of SMA wires (superelastic, Martensitic, …)**
- **Resin system (thermoset and thermoplastic matrices)**
- **Lamination sequence of SMA wires (SMA wires volume content, flexural inertia, pre-stressed wires)**
- **Textile hybridization techniques (integration of SMA wires within reinforcing fabric, placement within the laminate)**

SMART composites with higher damage tolerance

Experimental activities: single impact tests

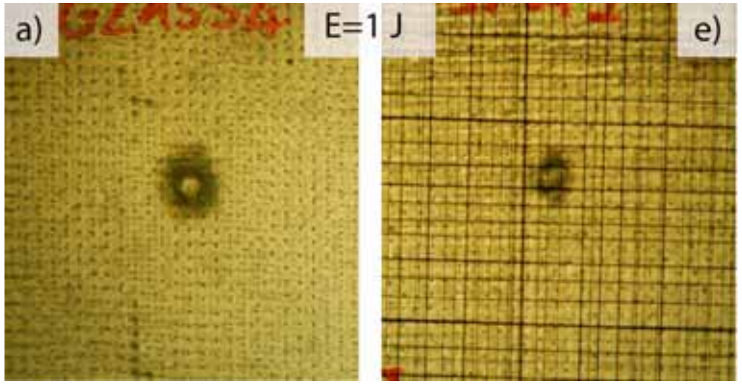
Force-Displacement curves



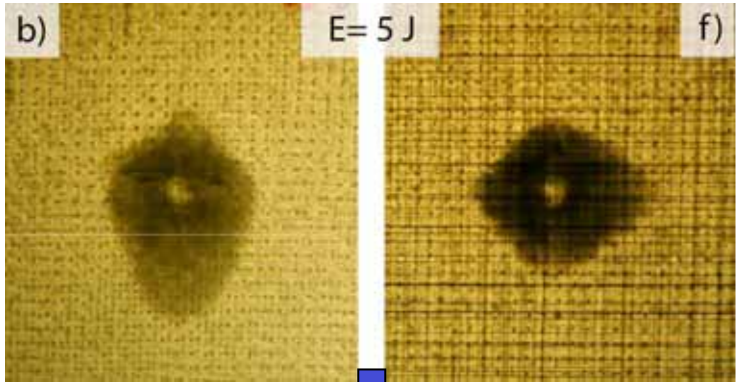
SMART composites with higher damage tolerance

Experimental activities: single impact tests

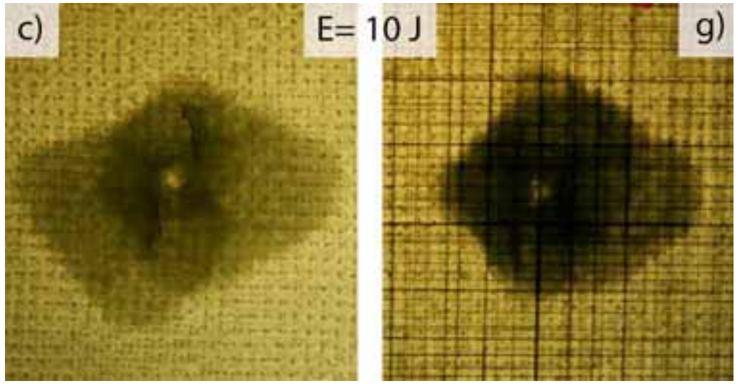
A significant influence of SMA hybridisation in decreasing the extension of the damaged area was observed by means of visual inspection.



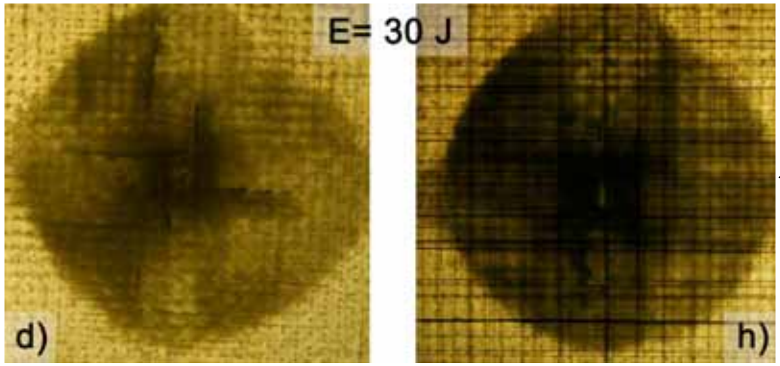
Standard Hybrid



Standard Hybrid



Standard Hybrid

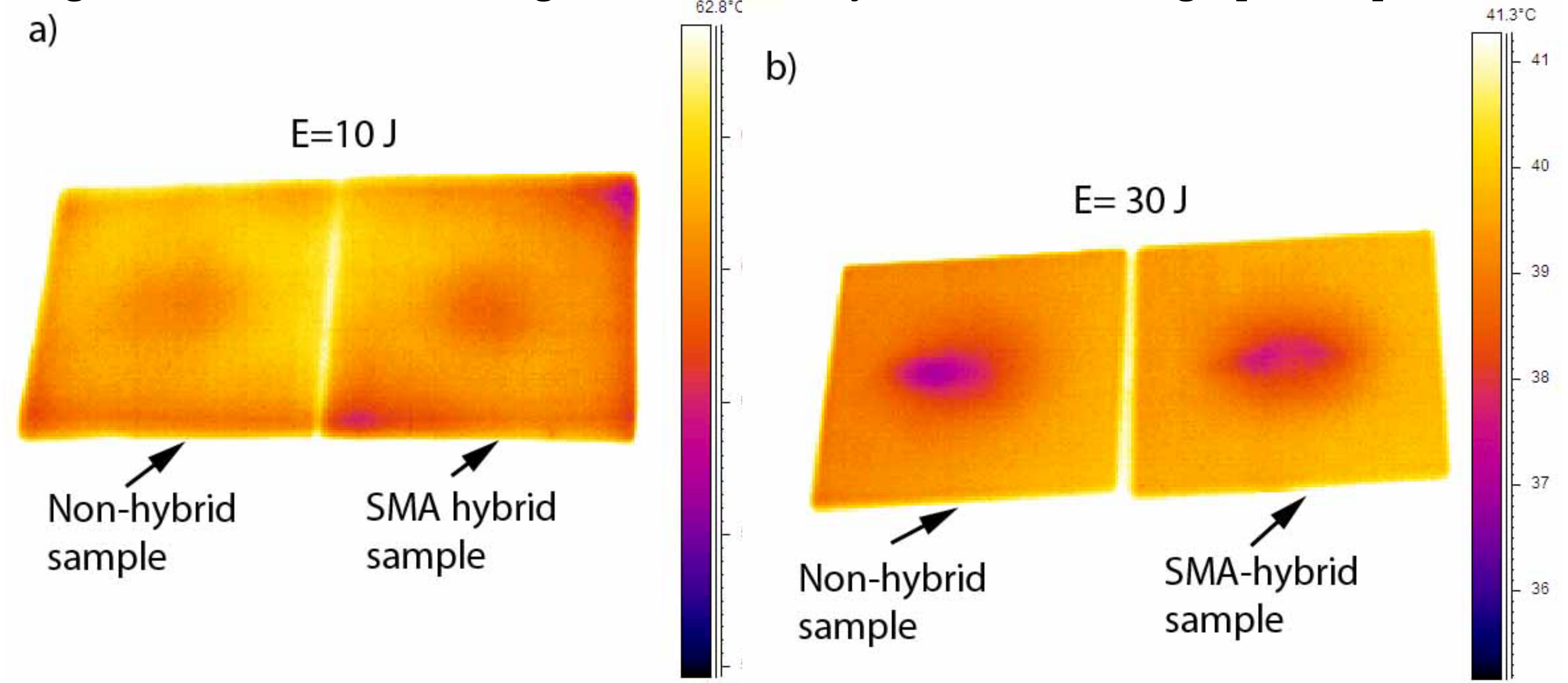


Standard Hybrid

SMART composites with higher damage tolerance

Experimental activities: single impact tests

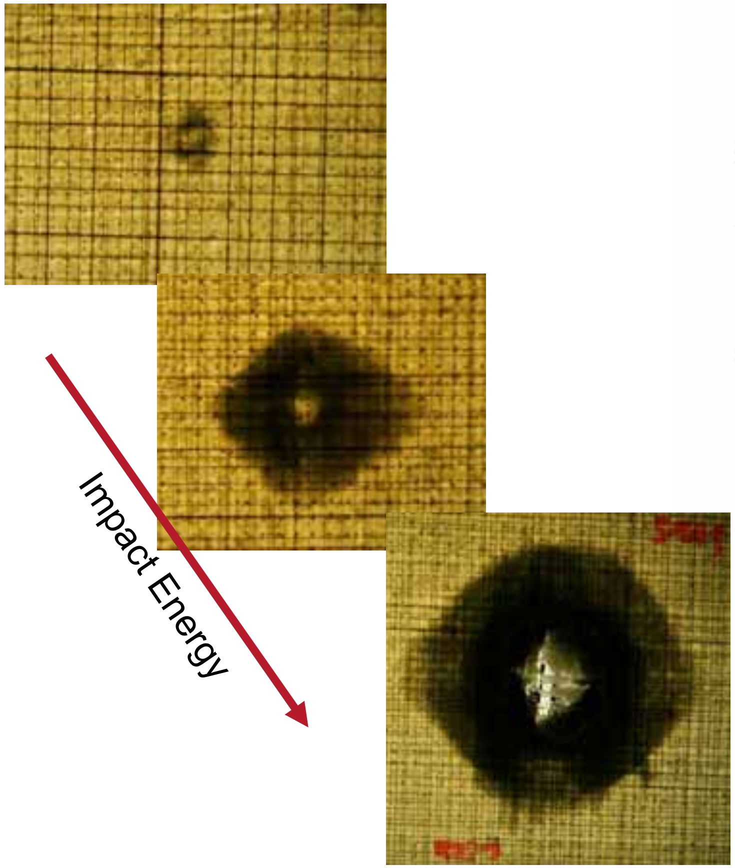
A significant decrease of damage was observed by means of thermographic inspection.

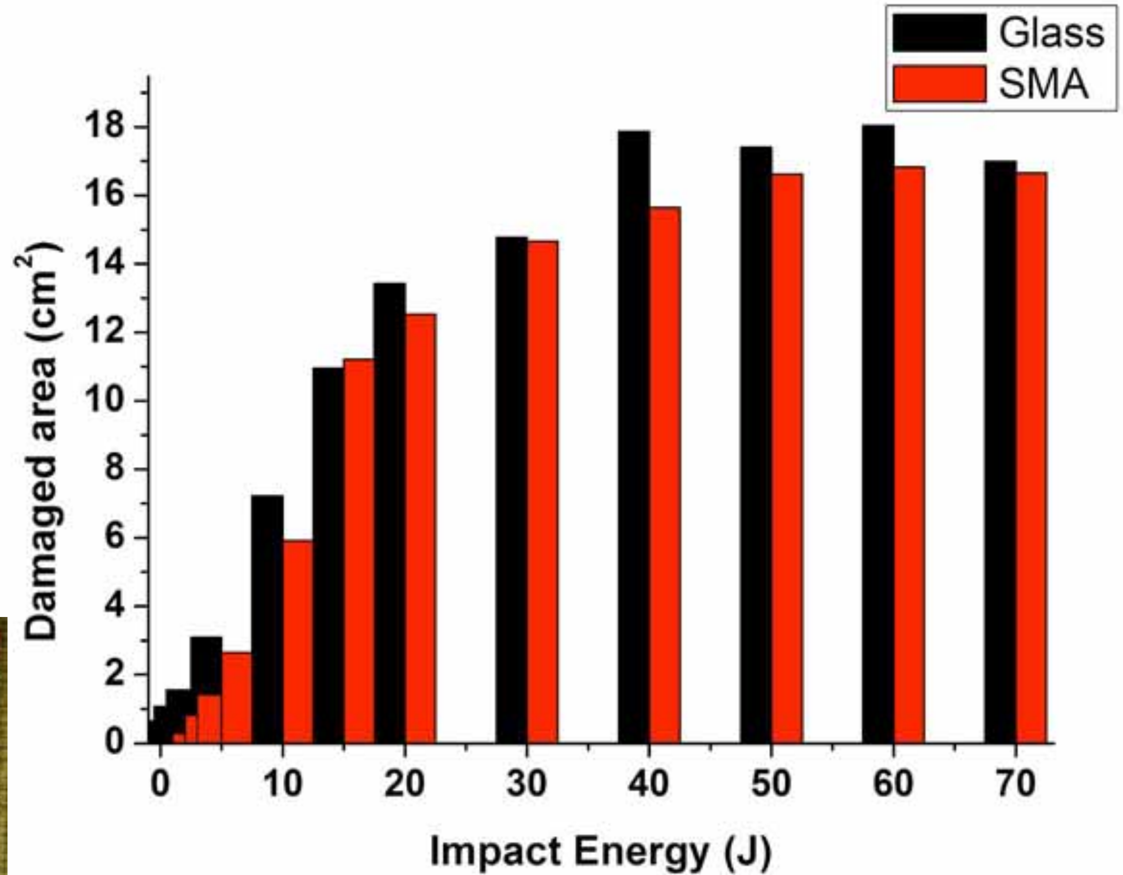


Thermograms of both standard and hybrid samples impacted with energy levels equal to 10 J (a) and 30 J (b).

SMART composites with higher damage tolerance

Experimental activities: single impact tests



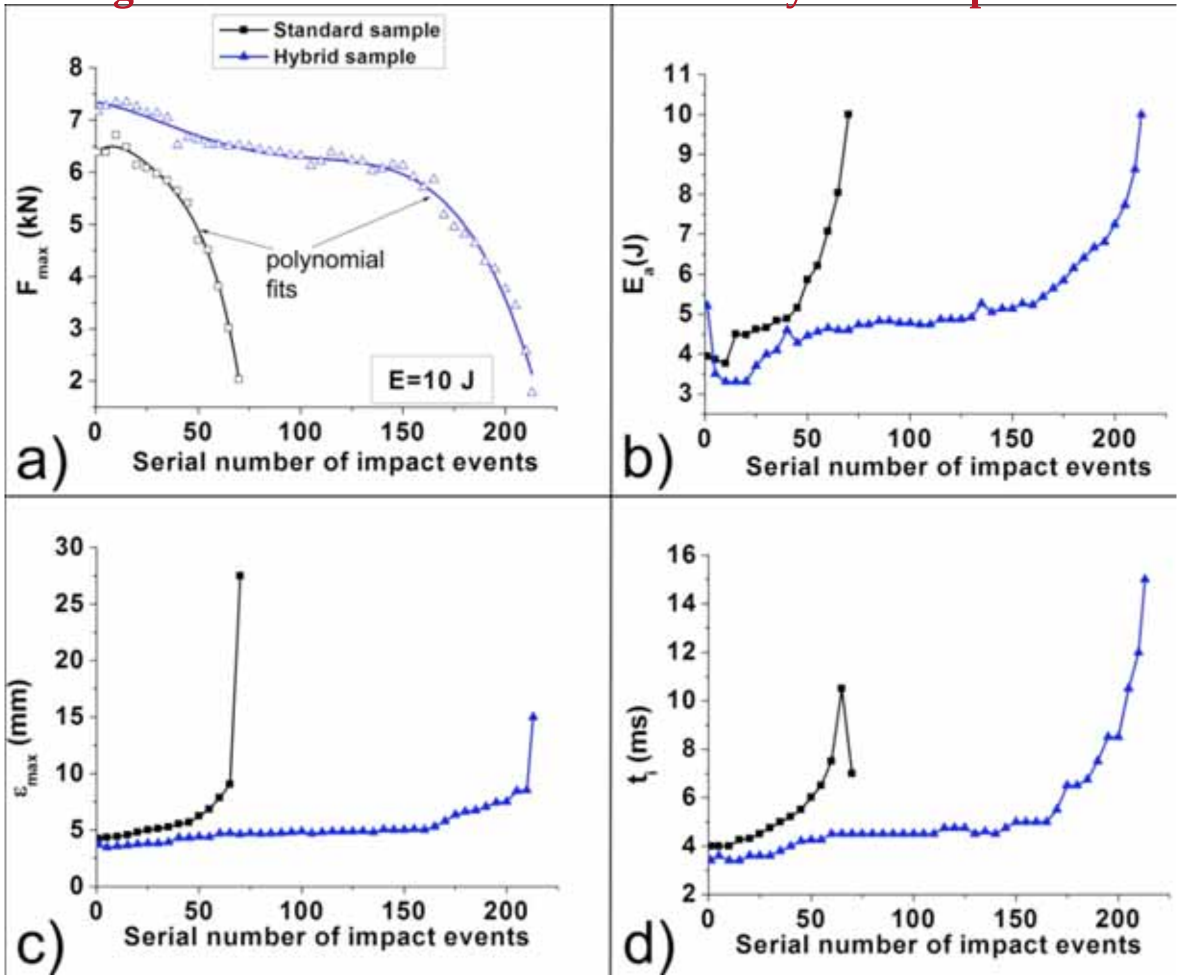


Usable diagram

SMART composites with higher damage tolerance

Experimental activities: repeated impacts tests

A significant increase was observed for hybrid samples.

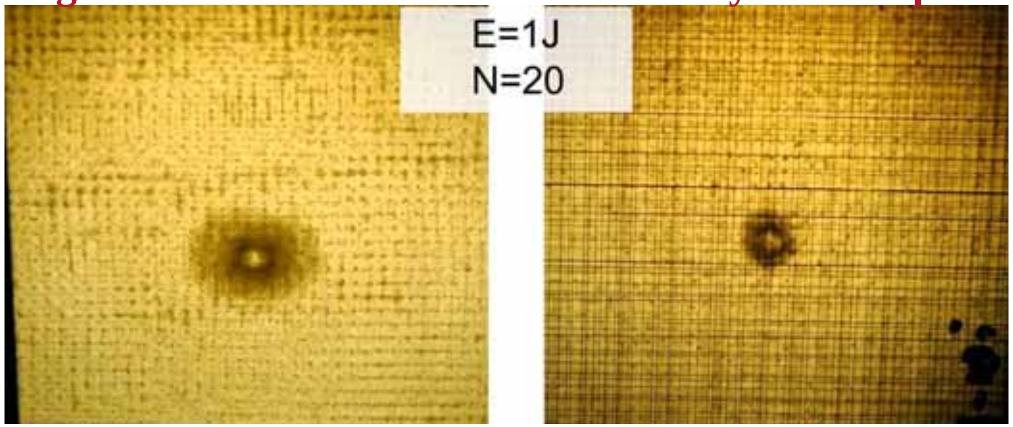


The samples were subjected to repeated impacts up to fracture. Results were plotted as peak load (F_{max}), absorbed energy (E_a), contact time (t_i) and maximum displacement during impact (ε_{max}) as a function of impacts number.

SMART composites with higher damage tolerance

Experimental activities: repeated impacts tests

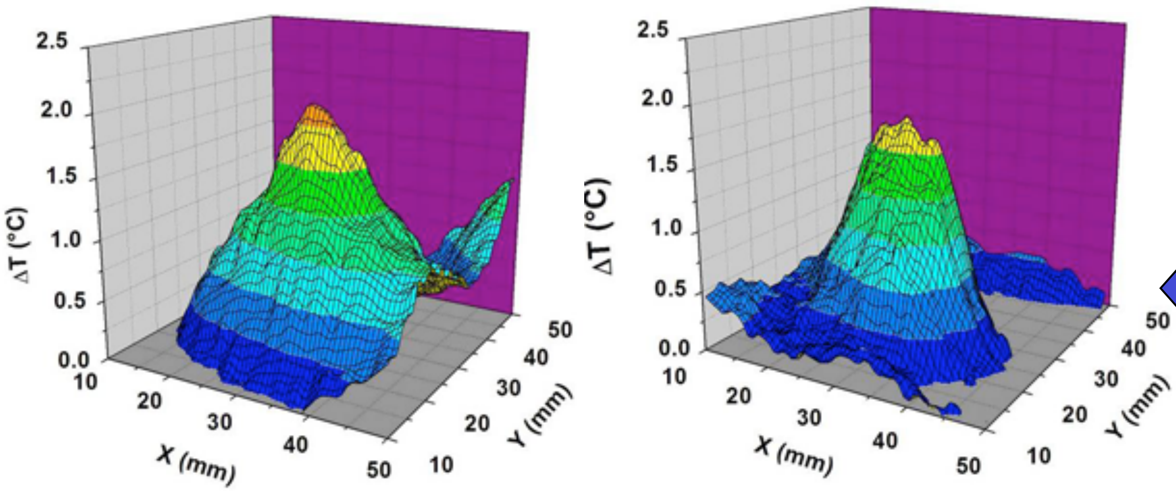
A significant increase was observed for hybrid samples.



Standard sample - 5 J - 20 impacts

Hybrid sample - 5 J - 20 impacts

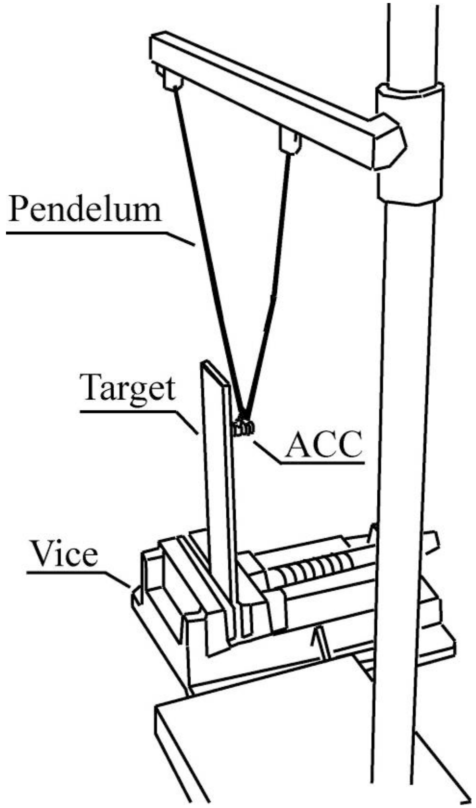
Photographs of damaged samples after 20 impacts at 1 J.

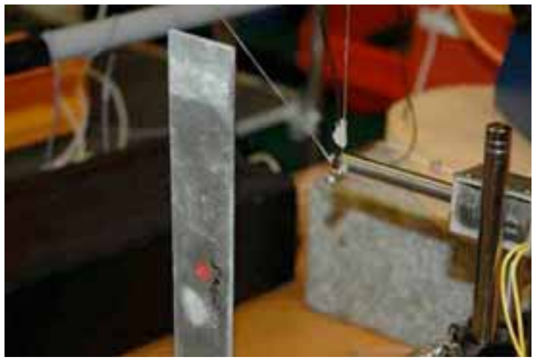


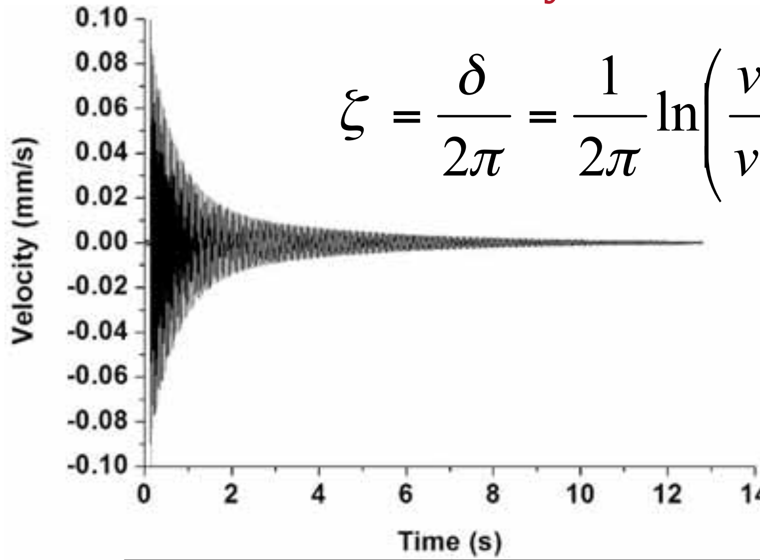
3D surface plots for both standard and hybrid samples after 20 impacts at 5 J.

SMART composites with higher damping properties

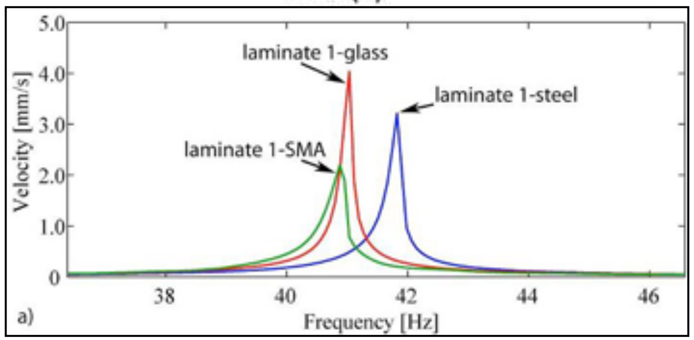
Experimental activities for high damping laminates: laser vibrometry







$$\zeta = \frac{\delta}{2\pi} = \frac{1}{2\pi}\ln\left(\frac{v_1}{v_2}\right)$$



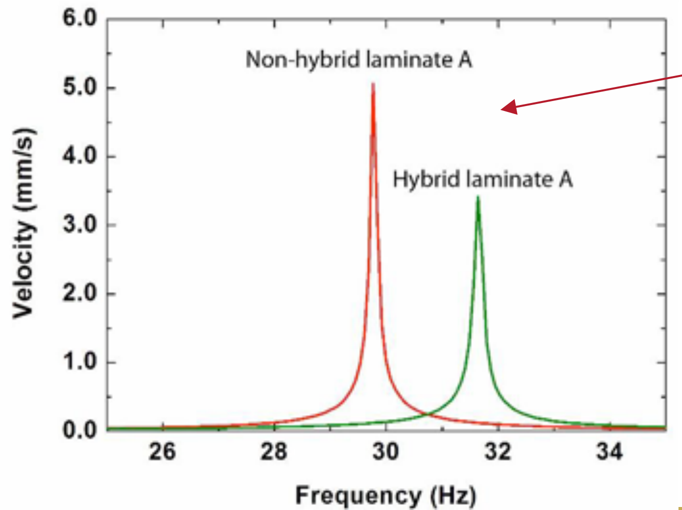
By measuring the vibration modes of a clamped cantilever, the influences of both SMA wires (martensitic and superelastic) on the vibration characteristics of the laminated plates were evaluated.

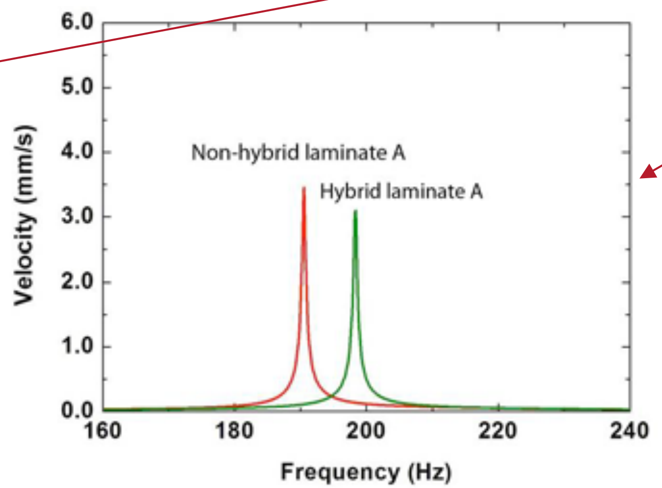
SMART composites with higher damping properties

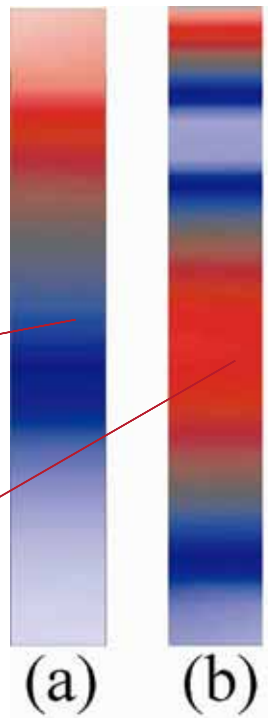
Experimental activities for high damping laminates: laser vibrometry

In both cases a significant increase of damping was observed for hybrid laminates

	1° Harmonic			2° Harmonic		
Sample	**Damping (%)**	**Velocity (mm/s)**	**Freq. (Hz)**	**Damping (%)**	**Velocity (mm/s)**	**Freq. (Hz)**
Non-hybrid laminate	0.15	4.64	29.8	0.14	3.85	190
Hybrid laminate with martensitic wire	0.19	3.82	31.9	0.15	3.47	199







Mode shapes of the composite samples

SMART composites with higher damping properties

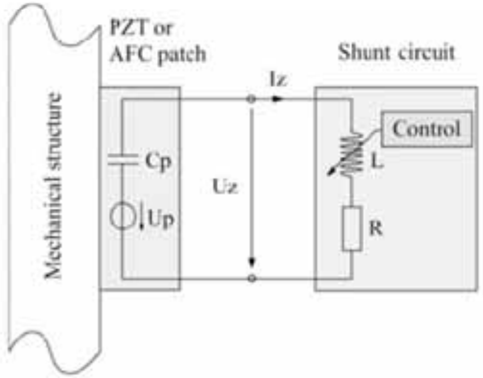
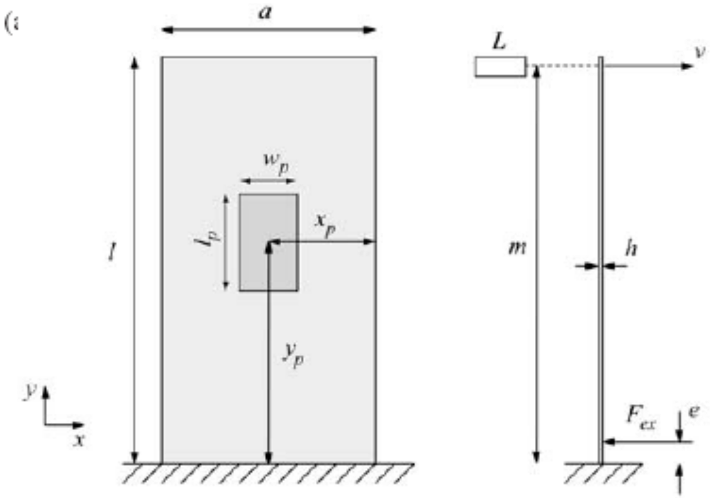
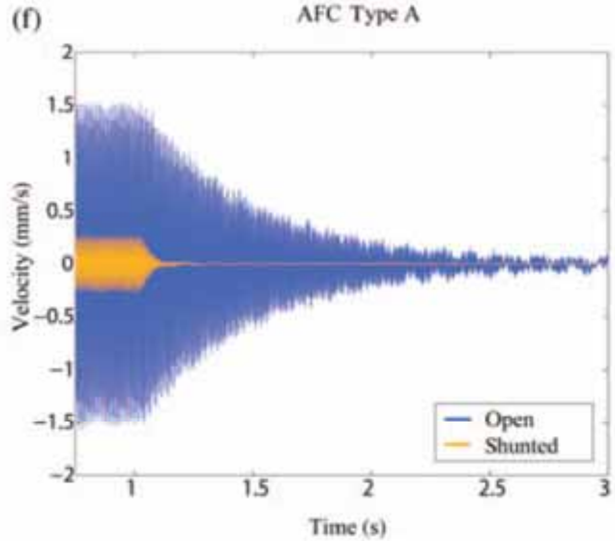
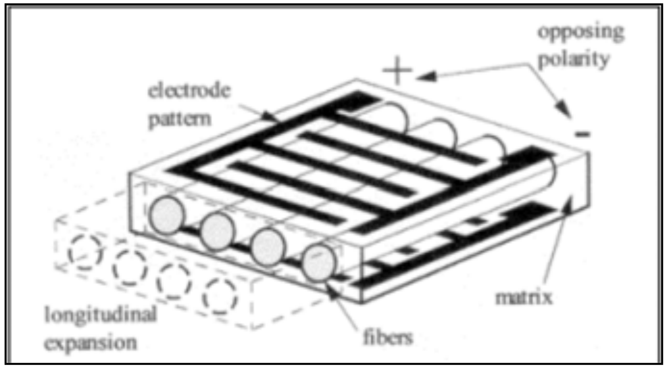


Figure 2. Adaptive R-L shunted piezoelectric patch.







Structural Vibration Control via R-L Shunted Active Fiber Composites

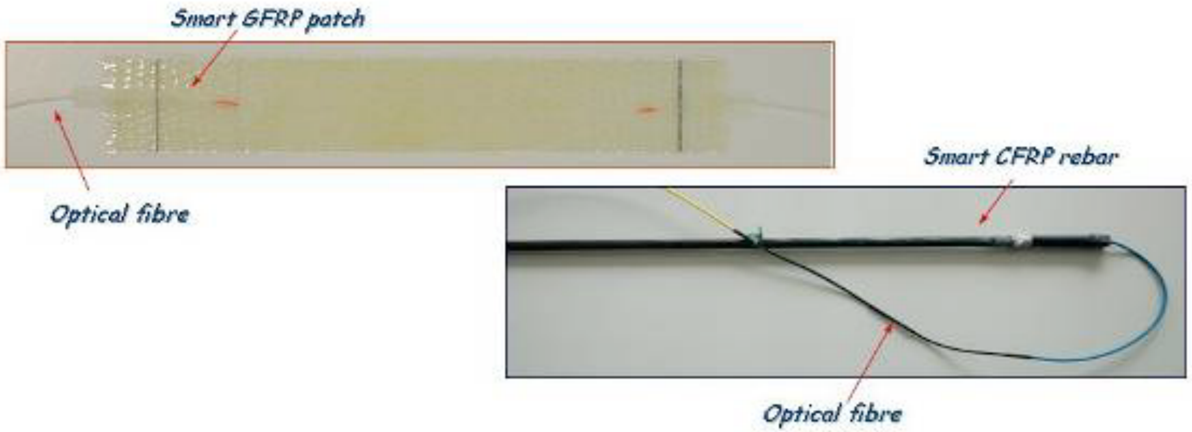
Alberto Belloli, Dominik Niederberger, Stanislaw Pietrzko, Manfred Morari and Paolo Ermanni

Journal of Intelligent Material Systems and Structures 2007; 18; 275 originally published online Dec 13, 2006

SMART composites with sensing capacity

Embedding FBG sensors within composite laminates

Structural health monitoring using sensors embedded in reinforcing components.

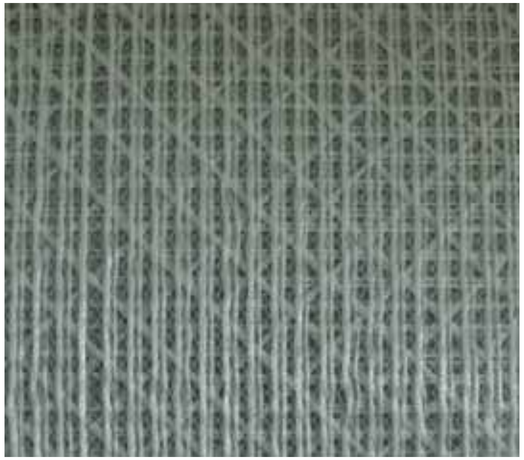


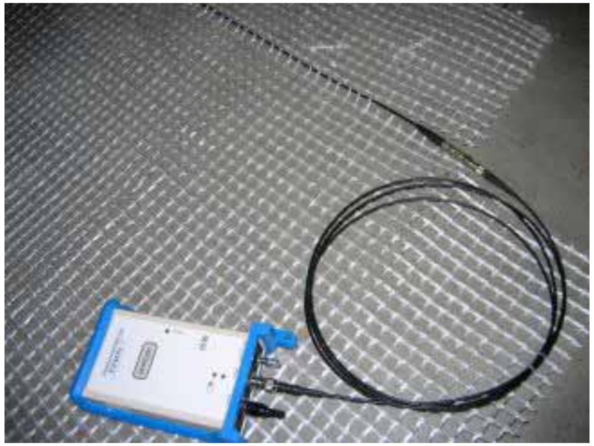
SMART composites with sensing capacity

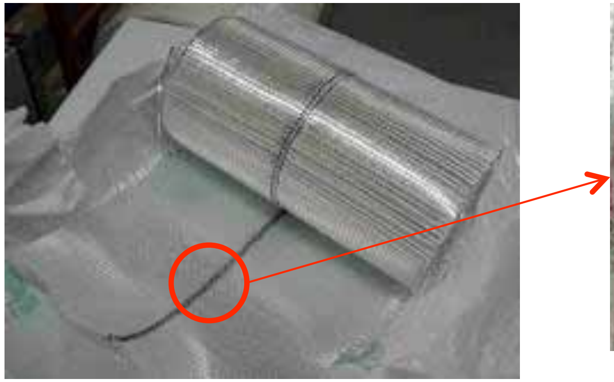
Embedding FBG sensors within composite laminates

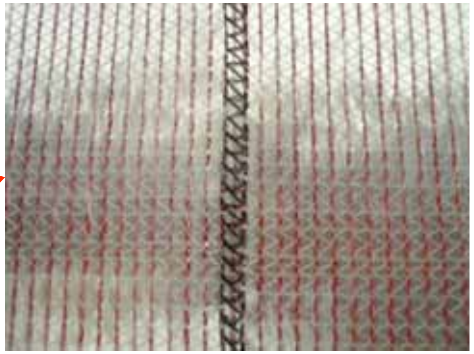
Semi-finished products embedding sensors.

Adaption of textile process





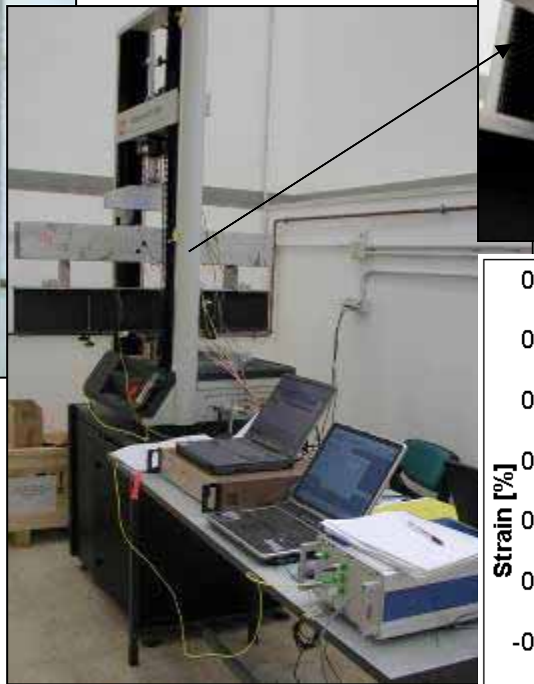


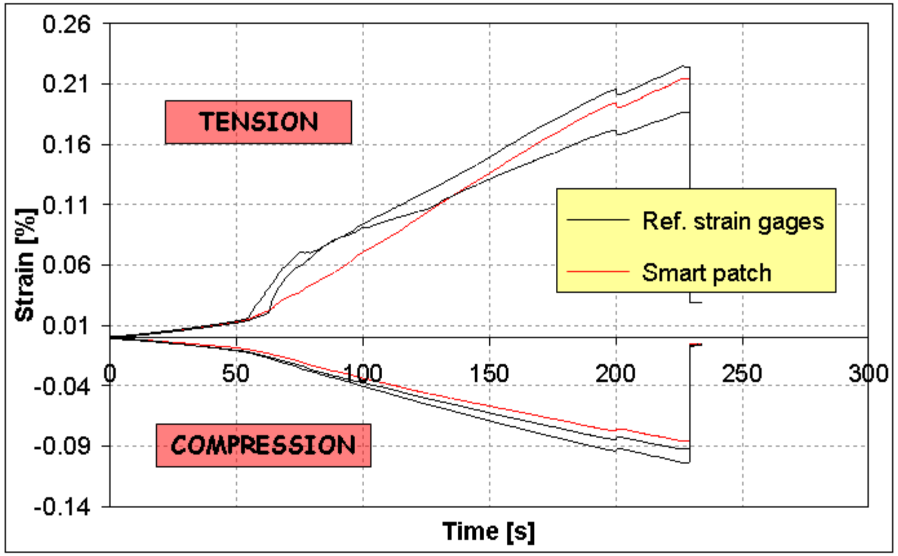


SMART composites with sensing capacity

SMART Sensors

Sensors calibration by mechanical characterization and metrological validation





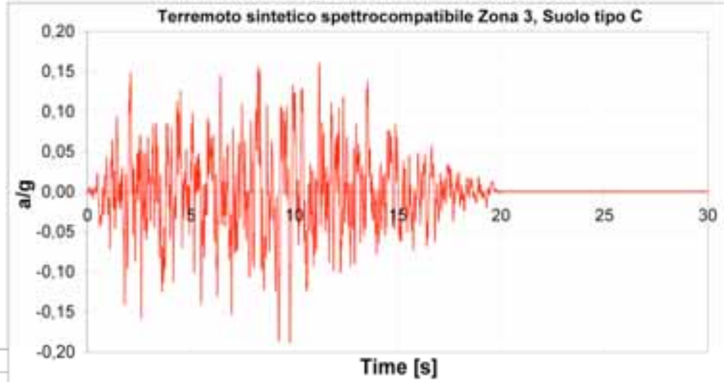
Static tests

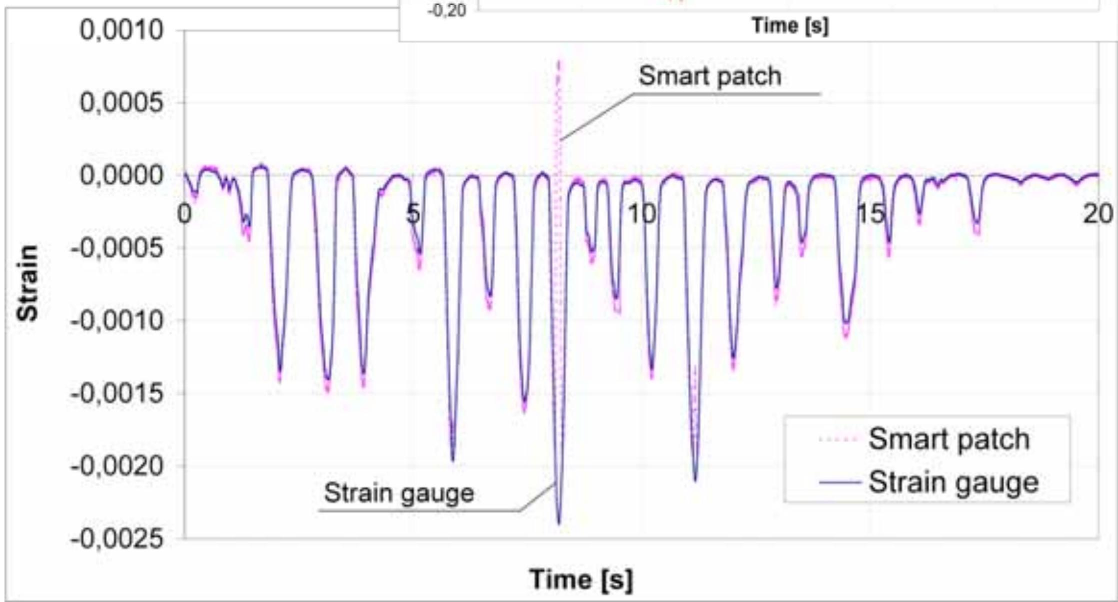
SMART composites with sensing capacity

SMART Sensors

Sensors calibration by mechanical characterization and metrological validation

Dinamic tests

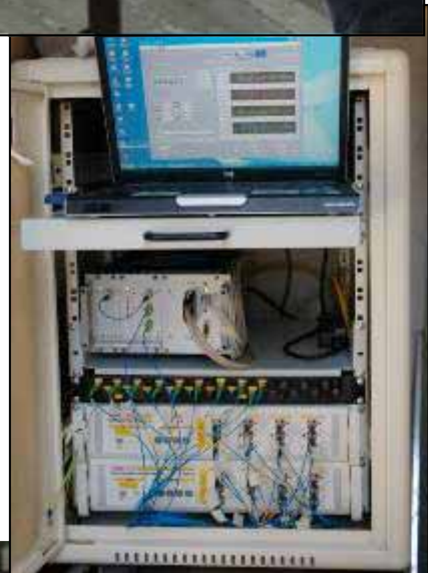




Experimental activities: remote structural health monitoring

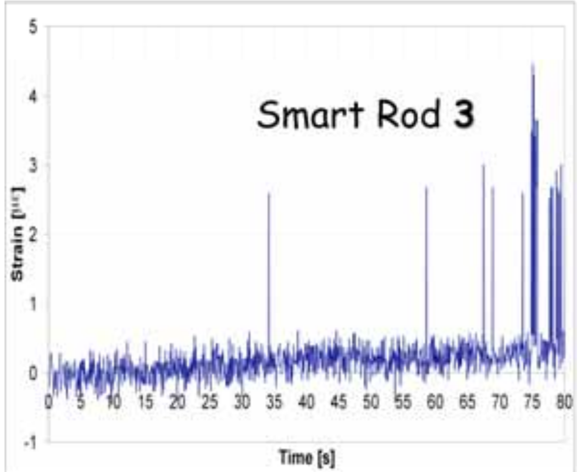
Autostrada SA-RC, Ponte Torrente Casale

Local Monitoring System (LMS)



SMART composites with sensing capacity

Experimental activities: remote structural health monitoring

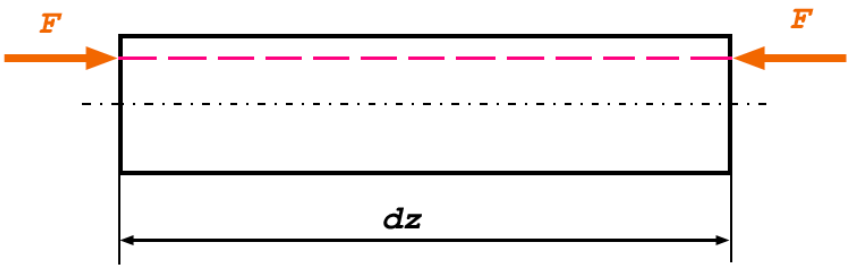


On-site unit

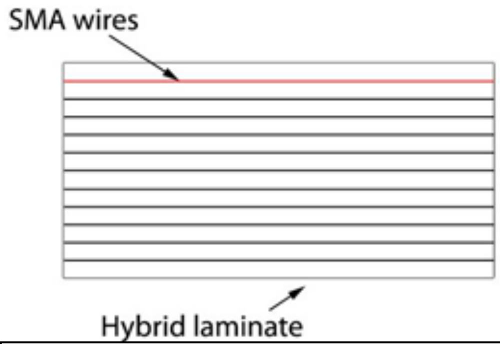
Remote control

SMART composites with actuating capacity

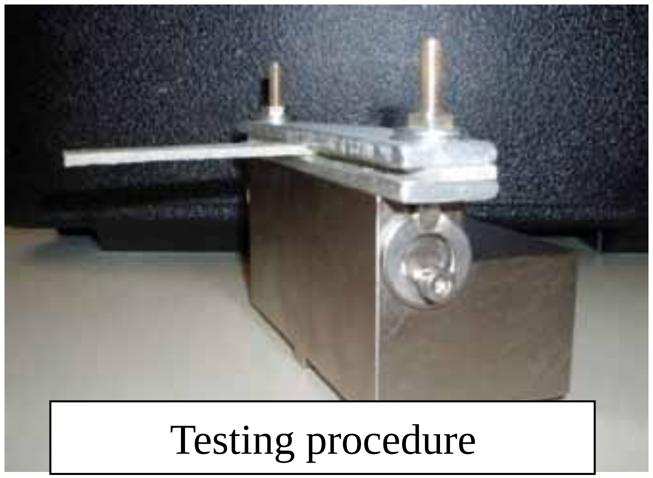
The capability of SMAs to recover their original shape when heating after large deformation was exploited to obtain hybrid composites with morphing capacities.



Physical principle

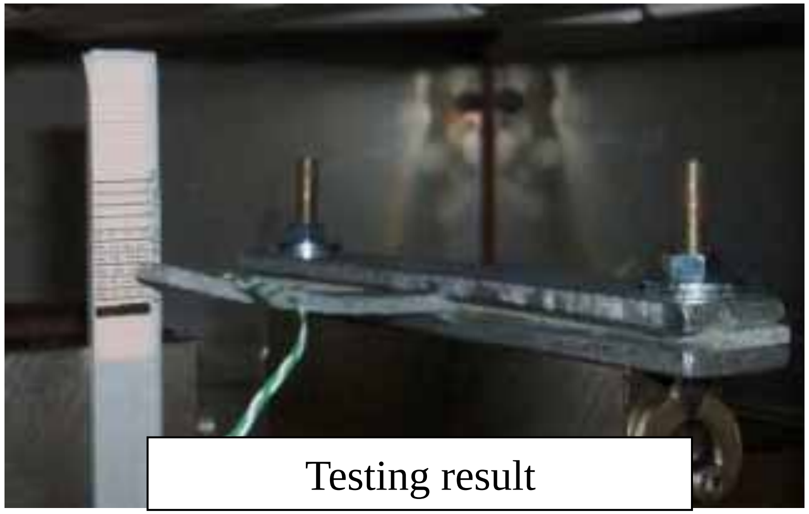


Hybrid laminate integration



Testing procedure

After heating



Testing result

SMART composites with actuating capacity

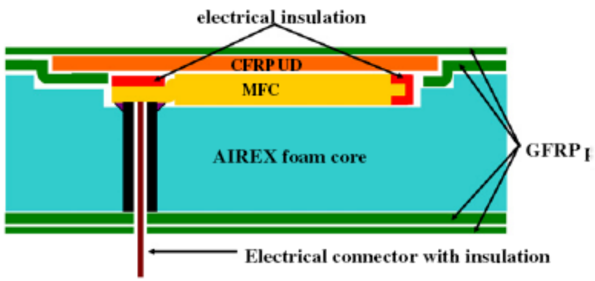


Figure 8. Schematic cross section of the active sandwich panel.

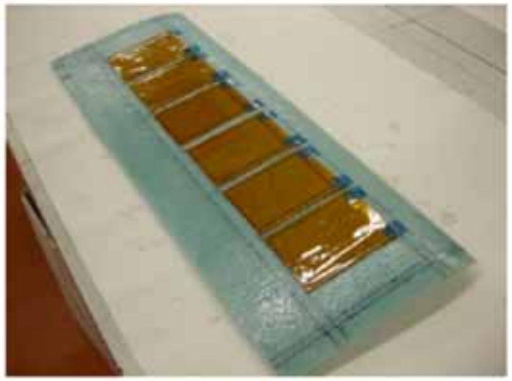


Figure 9. MFCs embedded in core material before covering with UD CFRP.

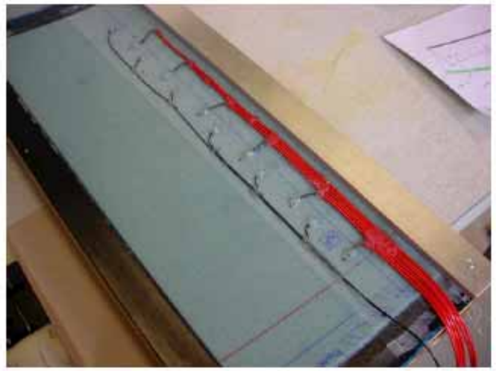


Figure 10. Electrical contact of MFCs through the sandwich.

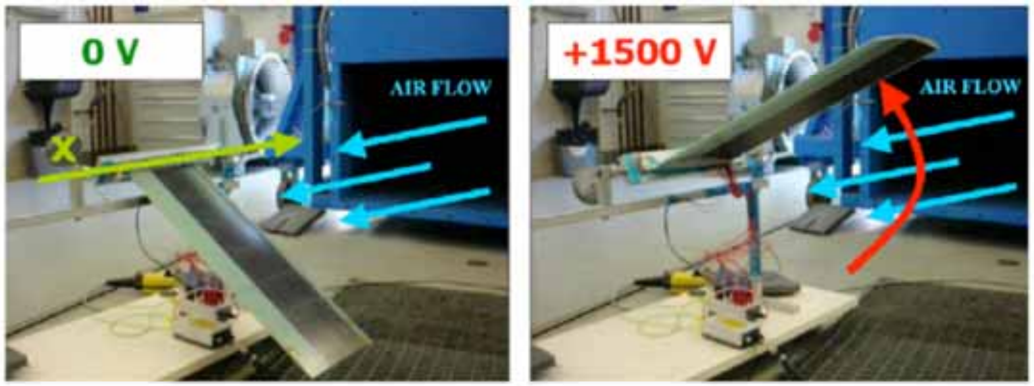
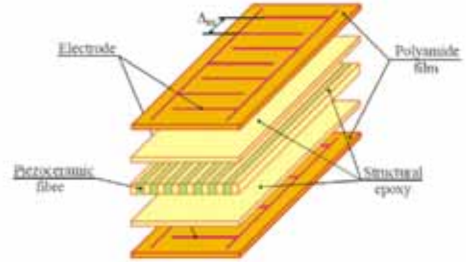


Figure 13. Active wing with deactivated and activated MFCs in air flow.

ongitudinal piezoelectric effect along the length of the fibers.



Active wing design with integrated flight control using piezoelectric macro fiber composites

Rolf Paradies and Paolo Ciresa

Smart Mater. Struct. ***18*** *(2009) 035010 (9pp)*

Conclusion

The use of SMA wires within a composite materials helped in gaining

-Enhanced impact properties

-Enhanced damage tolerance in the case of low energy impacts

-Enhanced vibration damping capacity

-Realization of composites with actuating function

Main issues are:

-Optimization of the design of the hybrid composite material

-Hybridization of structures and semifinished products

Thanks to …

My tireless **colleagues in CETMA** for their work and precious outcomes in several R&D activities

And **YOU** for your attention**!**

Centro di Progettazione, Design & Tecnologie dei Materiali

Materials and Structures Engineering DEPARTMENT

Technologies and Processes AREA

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