Polymer-based composites for aerospace: an overview of IMAST results

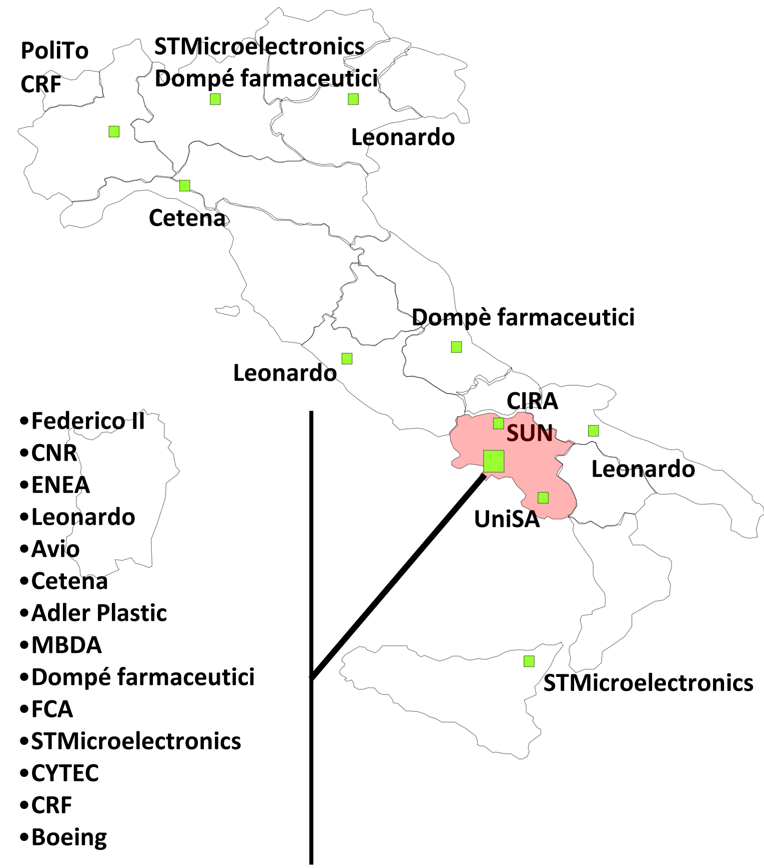
IMAST - Technological District on Engineering of polymeric and composite Materials and STructures

IMAST role

IMAST plays the role of **Knowledge Integrator**

It is set up as a **modern Corporate Research Centre,** where the largest italian companies, the University and Public Research Institutions perform together research activities in the field of **the engineering of polymeric and composite materials**

IMAST operates as a **holding** of industrial and public laboratories and create mixed groups of public and private researchers on specific research projects



IMAST: the consortium

PUBLIC INSTITUTIONS

- National Council of Research
- Italian National Agency for New Technologies, Energy and Sustainable Economic
- Polytechnic of Turin
- University of Naples "Federico II"
- Second University of Naples
- University of Salerno

BANKING SYSTEMS

- Istituto Banco di Napoli Fondazione

ASSOCIATED MEMBERS

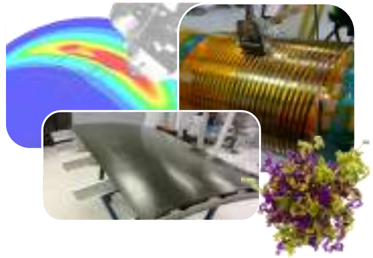
- Boeing Company

INNOVATIVE COMPANIES

- Adler Plastic
- AnsaldoBreda
- Avio
- Centro Ricerche Fiat
- Cetena
- CIRA
- CYTEC
- Dompè farmaceutici
- Fiat Chrysler Automobiles
- Leonardo
- MBDA
- STMicroelectronics

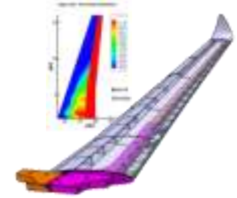
IMAST application fields

MANTA – Thermoplastic nanocomposites with improved damping and impact properties



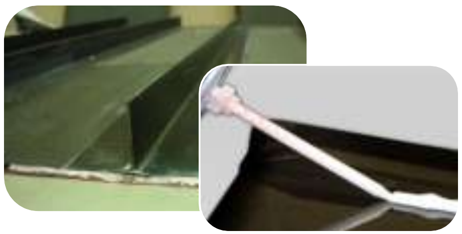
TECOP – Thermoplastic composite fuselage components (manufacturing processes optimization)

Green Regional Aircraft – Analysis of fire performance of composite components



Green Regional Aircraft 2 – Thermal modeling of composite in fire conditions, innovative repair solutions and functional coating to improve self cleaning and hydrofobic properties of wing

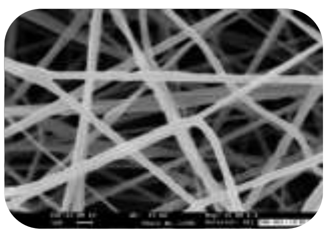
ARCA – Composite panel with improved vibro-acoustic properties and weight reduction



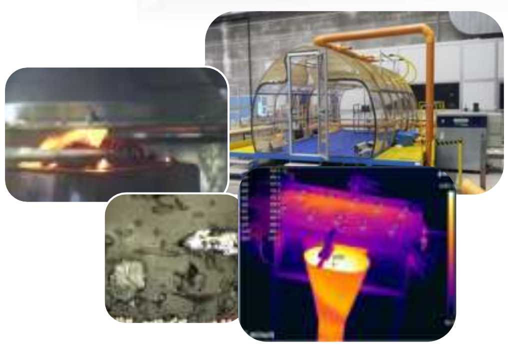
ASAP – Innovative thermosetting adhesive for out-of-autoclave bonding process (process optimization)

AERONAUTIC

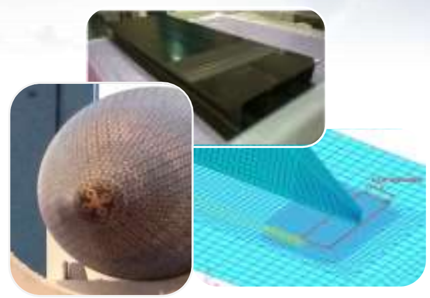
CESPERT – Thermoplastic composite emergency door with hail impact resistance and weight reduction



IMPRESA – multifunctional composites for pressure and humidity monitoring



COCET – composite interiors with improved fire resistance

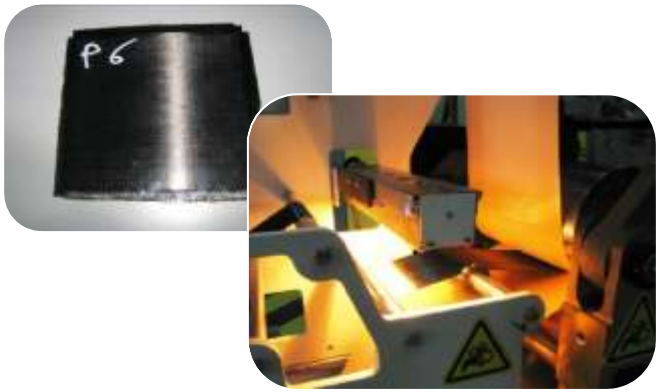


FUZI – Aeronautical polymeric composite Radome and multifunctional composites for structural health monitoring

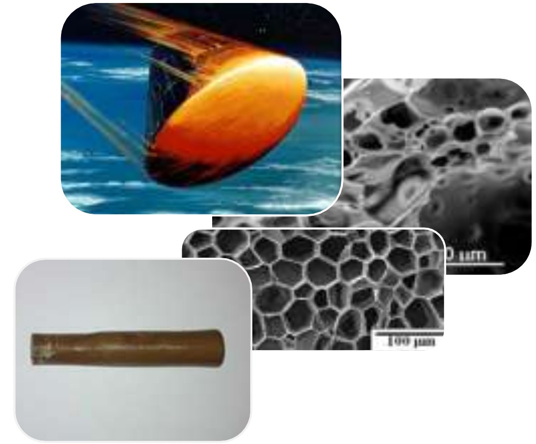
COGEA - development of a simplified methodology for qualifying composite materials for general aviation

MACADI – Computational models to improve the prediction for impact events involving composite structures

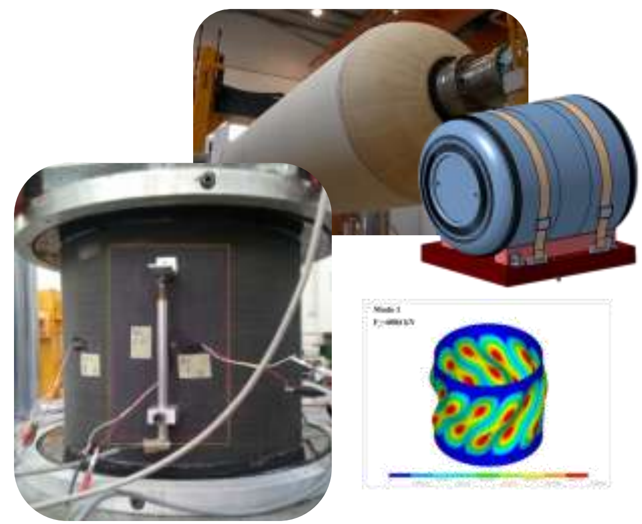
PRICE - Filament-winding technology to the production of motors cases for space launchers and epoxy prepreg system with long shelf-life and high thermo-mechanical performances (glass transition temperature 170 C and out life 6 months RT)



COCET – Polymeric composite ablative tile for atmospheric re-entry



PRADE – Polymeric composite system for the engine repair with improved mechanical performances



IMPRESA and **FUZI** – Multifunctional composite systems for structural monitoring

MATERIALS FOR SPACE LAUNCHERS
materials and processes

A method for manufacturing prepregs comprising the steps of **developing a polymeric formulation**, **impregnating fibers** with the polymeric formulation and **filament winding process** optimization for **motors cases of space launchers** realization.

Two epoxy components (based on Bisphenol A diglycidyl ether - DGEBA) and a reactive diluent (thixotropic agent) have been cured with diaminodiphenylsulfone (DDS) in order to control the rheological features with respect to temperature and the reaction conversion degree **(b-staging)**. DDS curing agent was selected to achieve low reactivity at room temperature and improved thermo-mechanical features at the end of the conversion cycle. Reticulation kinetic for the identified epoxy formulation has been studied by analyzing the dependency of viscosity with respect to temperature and conversion degree.

Prepregs, tow and tape, developed by using epoxy system show **long shelf-life** (**6 months RT**) and **high thermo-mechanical performances** (glass transition temperature about **170°C**).

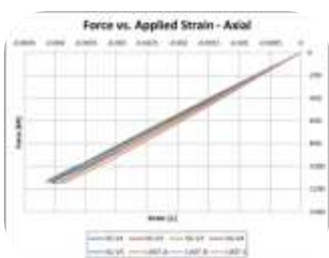
MATERIALS FOR SPACE LAUNCHERS

polymeric composite systems for the engine repair

1) adhesive application;
2) composite patch application;
3) flat panel repaired with vacuum bag process.

Vessel (Ø=400 mm) realized by FW

cylindrical skirt (Ø=400mm)



The **motor case** is, at the same time, the combustion chamber of the SRM and the structure subjected to the mechanical loads of the launcher. **Lightweight composite** structures are necessary in order to obtain the optimized mass ratio requested for the stage.

The Solid Rocket Motors (SRM) can be schematized as a **cylindrical pressure vessel** which mainly sustains the internal pressure and two **cylindrical Skirts**, connecting the SRM to the adjacent stages.

Impact damage can occurs during manufacturing and handling phase. So, a **repair procedure**, based on **composite patch application**, aimed at restoring the strength of the damaged component, was developed.

Polymeric composite patches have been obtained by developing a **prepreg polymeric system based on epoxy/phenolic resin** (formulation PRADE D) and **carbon fiber**.

Prepreg patches are applied and the **reticulation cycle has to be as short as possible and process temperature shall not exceed 60°C**.

The items have been subjected to **compression load** up to the collapse of the structure by demonstrating that the **repaired items collapse at a compressive load (about 1.000KN) not lower than the undamaged item.**

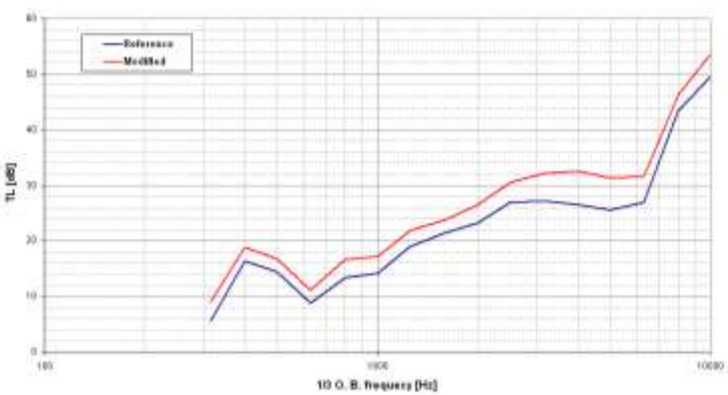
MULTIFUNCTIONAL COMPOSITES
with improved vibro-acoustic properties

In order to improve the passengers comfort by reducing the noise heard onboard, a **composite panel for fuselage** (designed for Boeing 787), with **improved damping properties** has been realized (solution patented).

The technological demonstrator has been obtained by inserting a visco-elastic damping layer (high loss factor) inside the carbon fiber composite laminate.

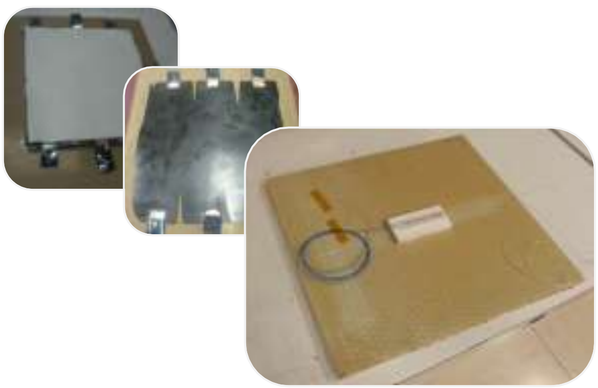
This solution exhibits a **weight reduction of 60%** respect to reference (aluminum panel with add on systems) with advantages in terms of fuel consumption and CO_2 emissions.

The analysis of the vibro-acoustic performance was carried out in an acoustics room, through measurements of noise reduction and extrapolation of transmission loss data. In particular, an **improvement of acoustic properties of 3dB** has been achieved.



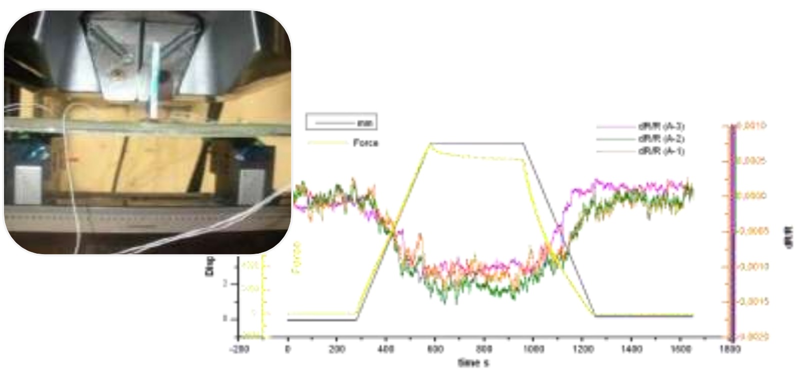
Comparison of transmission loss (dB) between carbon fiber reinforced panel (blu line) and the system obtained by inserting visco-elastic damping layers inside carbon fiber laminate (red line)

MULTIFUNCTIONAL COMPOSITES
with sensing properties



A **multiscale composite panel with piezoresistive properties** has been developed by inserting a thermoplastic nanocomposite film in a epoxy fiber-reinforced composite laminate.

The thermoplastic film, realized by **thermoforming process of phenoxy resin** charged with **CNT**, shows **piezoresistive properties**: the electrical conductivity of composite vary when a strain is applied. Thermoplastic piezoresistive layer has been inserted between two laminates of epoxy composite reinforced with glass fibers (autoclave process).



This solution provides an integrated and distributed healt-monitoring over the entire surface of the panel. **Strain-sensing properties** were verified by testing with **3-point flexural test** the piezoresistive panel powered with a constant current of **0,5mA**.

Thermoplastic system is compatible with epoxy fiber-reinforced composite to avoid delaminations: **short beam strenght test** is not influenced by the presence of nanocomposite thermoplastic layer (**75MPa**).

This solution is an alternative to add CNT directly to the epoxy matrix that leads a dramatic increase of viscosity and poor processability. The thermoplastic nanocomposite films are a self-standing system (sheet) that can be easily integrated during the lamination process in a manufacturing fibers composite process.

MULTIFUNCTIONAL COMPOSITES
with electromagnetic properties

A polymeric composite aeronautical Radome with **frequency selective surface** (FSS) has been realized in order to prevent coupling from nearby transmit antennas, that may interfere with the electronic circuitry.

The developed solution acts as a **pass band filter** at a given frequency band, while behaving as an **absorber out of the operating band**.

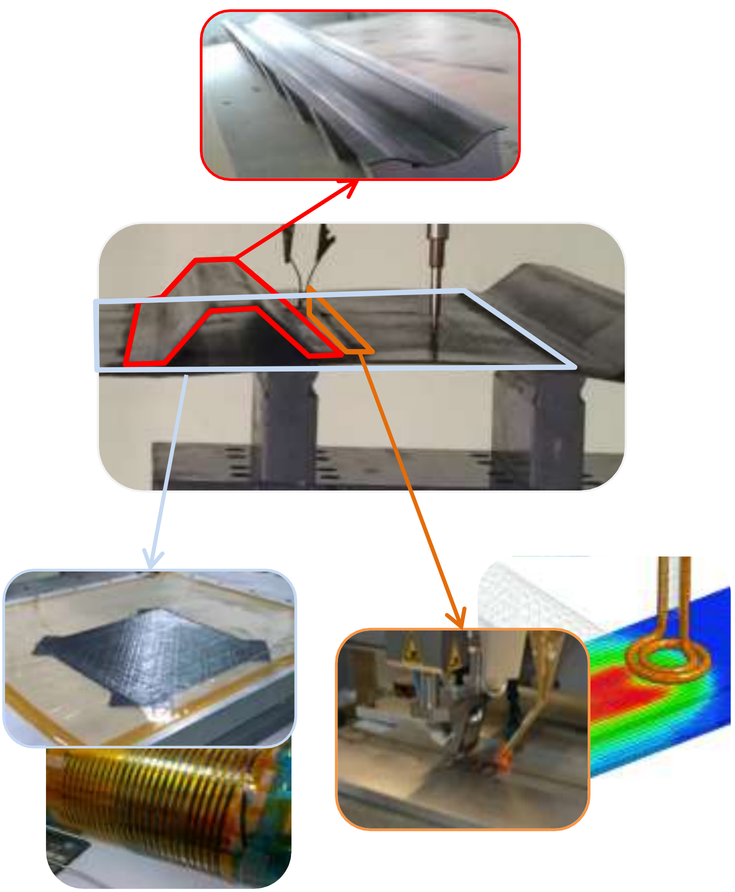
The conical demonstrator has been realized by using hand-lay-up lamination process, based on **cyanate ester prepreg, reinforced with astroquartz fibers**.

The EM functionality has been obtained by adding a metallic (copper) functional layer (flame spray process) with a specific array geometry on the radome surface.

The radiofrequency tests showed that, **in the range 8-40 GHz, the FSS radome acts as a pass-band filter centered at 13.5GHz**, with a transmission loss lower than 1.5dB. Out of the operating band, the reflection is higher than 15dB.

Composite **Radome** meets the **thermomechanical** requirements of aeronautical applications **(Tg 330°C).**

ADVANCED MANUFACTURING PROCESSES
for structural thermoplastic composites



A **full thermoplastic composite airliner fuselage panel** has been manufactured by using polyetheretherketone (**PEEK**) reinforced with **carbon fibers** (APC2, Cytec) quasi-isotropic:

- the **skin** has been realized through **AFP technique** (0/45/-45/90°). The AFP process has been conducted by keeping the laminate above **Tm (340°C)** during manufacturing process.
- the **stringers** have been realized through **thermoforming process** (no defects are reported by **calorimetric** analysis and **thermographic inspection**)
- stringers and skin have been welded by **induction welding**. This technique has the advantages compared to classical joining processes: not introducing mechanical stress, not having the infiltration of liquids and holes in the laminates, can be automated, not provide contact between heating source and components to be welded and surface preparation is not necessary (typical problem of adhesive techniques).

The study showed that an optimization of *in situ* consolidation AFP should be performed, in order to obtain high mechanical properties of laminates made by AFP (comparable with autoclave).

The developed solution (without post-processing autoclave or compression molding), showed that it's possible to realize thermoplastic composite components with a **costs reduction (about 20%) respect to autoclave process and thermosetting materials**: high level of automation, improvement of the product quality (high repeatability in the positioning of the material), reduction of waste material, energy saving due to the absence of refrigerators (necessary to maintain thermosetting prepreg) and eliminate the autoclave.

ADVANCED MANUFACTURING PROCESSES
for structural thermoplastic composites

A **full thermoplastic composite emergency door** for a Regional Aircraft (ATR42) has been realized by using automated fiber placement technique and thermoforming process applied to carbon fiber reinforced polyetherether ketone (PEEK) and polyphenylene sulfide (PPS).

The **skin** has been realized by using **AFP**, but in this case, in order to meet the mechanical requirements of aeronautical sector, the component has been post-processed in autoclave.

This solution meets **aeronautical requirements of hail impact test** (damage by hail strikes 50J has been negligible).

Moreover, a **weight reduction of 39%** respect to aluminum solution has been achieved.

FIRE ENGINEERING
for aircraft interior panels

An **aircraft interior panel** has been designed and realized by using carbon fiber (fabric 3K-70 plain wave) reinforced composite. The matrix is a phenolic resin with flame retardant properties.

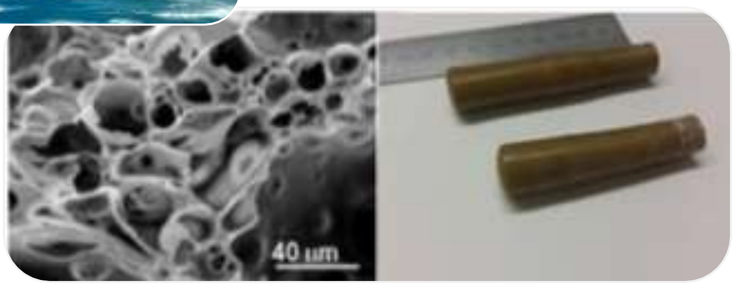
This solution **meets requirement of Federal Aviation Regulation** (FAR) 25.853 App. F Part III: **no flame penetration** has been observed whitin 5 minutes after the flame source exposure and the **maximum temperature** measured 10 cm above the surface is **lower than 204°C**.

Composite system ensures a **weight reduction of 10%** compared to the traditional lining solution, resulting in a lower fuel consumption and CO_2 emissions.

An experimental **tool to replicate the flame penetration test on small scale** has been realized. This tool can be used to obtain information about the properties of flame resistance of composites, reducing the number of experimental tests in large scale (and consequently the consumption of material).

It has been, also, developed a model that **optimizes the placement of smoke detectors on board** and improves passenger safety simulating the formation and propagation of smoke in the cabin of a plane during a fire.

FIRE ENGINEERING
for thermal protection systems



Space exploration missions often include entering atmosphere at hypersonic speed. A high enthalpy hypersonic shock forms around the spacecraft and kinetic energy is progressively dissipated into heat that is transferred to the surface of the spacecraft by radiation and convection. The entry into high-density atmospheres requires the use of ablative materials for **Thermal Protection Systems** (TPS). These mitigate the incoming heat through phase changes, chemical reactions, and material removal.

An **ablative tile** for atmospheric re-entry, thermoset-based matrix (phenolic) modified by nanocharges (fumed silica) and microcharges (pumice) has been realized.

The **plasma tests showed an ablation of only 6%**.

A FEM **model** has been developed in order to **describe the phenomenon of ablation**. In particular, the model calculates the recession of material as a function of the heat flow acting on the material at each instant of time. This model allows to reduce the number of experimental tests.

IMAST fire lab

IMAST has set up a numerical-experimental **Fire Laboratory – PIROS,** to **study the fire performances of composite** materials and to **develop new composites** for applications where fire issues are extremely relevant.

In particular, fire laboratory activities are:

- ❑ thermo-mechanical modelling of composites;
- ❑ analysis of the fire reaction and the fire resistance of materials;
- ❑ development of new composite materials with flame retardant properties.

Fire test apparatus

- ❑ Cone Calorimeter
- ❑ Flooring Radiant Panel (FRP) Horizontal Spread of Flame
- ❑ IMO/LIFT Vertical Spread of Flame
- ❑ Oxygen Index and High Temperature Oxygen Index
- ❑ Non Combustibility
- ❑ Thermal Conductivity
- ❑ Smoke Chamber

IMAST S.c.a.r.l
Piazza Bovio, 22
80133 Naples, ITALY
Ph./Fax +39 081 5519586

www.imast.it