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imat

INTELLIGENT MOBILE MULTIPURPOSE ACCURATE THERMO-ELECTRICAL (IMAT) MILD HEATING DEVICE FOR CONSERVATION OF CULTURAL HERITAGE ASSETS

Collaborative research project **2011-2014**

the IMAT project: first application of carbon nanotubes in art conservation

In November 2011, a kick off meeting was held at the University of Florence in Italy to launch the IMAT project under the European Commission's 7th Framework Program (FP7). During the three year length of the project, coordinated by the University of Florence, a European consortium of researchers representing expertise in art conservation, nanotechnology, and thermo-electrical engineering will advance technologies and develop new technology to invent devices specifically designed for highly accurate mild heating in conservation of artworks and other cultural heritage assets, while also developing new treatment methodologies.

The Challenge

The advancement of conservation materials and instrumentation is of fundamental importance in the process of preserving artworks and other cultural heritage assets. Sophisticated and accurate instrumentation allows conservators to treat artworks more selectively and within the margins of minimal intervention and risk, while achieving the maximum result.

The IMAT project focuses and responds to a critical omission in current conservation treatment instrumentation for mild heating. Highly accurate and versatile application of mild heat is essential for success in most structural treatments of various cultural heritage objects (paintings, works on paper, textiles, objects, and others), yet devices presently available to conservators in all areas of the profession are unable to guarantee the desired accuracy, control or uniformity. The IMAT project will develop nanotechnologies to be integrated in the creation of a series of new highly accurate, versatile and mobile "smart" mild heating technologies and devices, each designed for specific use in art conservation with extraordinary properties made possible with innovative, yet-to-be-created, highly conductive carbon nanotube (CNT) materials.

Project Objectives

The IMAT project will research the application of carbon nanotubes for mild heating, focusing on their thermal and electrical properties that offer new opportunities to design radically new accurate mobile mild heating technology and devices - in the form of flexible mat heaters - with desirable qualities for art conservation. Such heating mats fitted with the to-be-designed sensors and controls could be designed in ultra thin, transparent, and woven forms, and may be designed as gas permeable membranes to permit the migration of vapours and airflow so often used in combination with mild heating in treatments. The project will involve art conservators during the initial design and field-testing phases so as to gain the best insight into design improvements, to optimize the range of potential applications of the IMAT and to develop new conservation methodology associated with the new technology.

Methodology

The project was conceived with a research-based objective and with a bottom-up design format of the IMAT concept and design, unique in the field, as well as with the associated methodology in order to improve the quality, accessibility and cost effectiveness of a fundamental tool for art conservators in Europe and globally. During the first year, in an interdisciplinary collaboration between scientists and conservators, the technical aspects of the IMAT will be researched and developed to achieve optimal designs and configurations of the CNT heaters leading to the first IMAT prototypes. In the second year of the project, field testing partners will submit the prototype designs to rigorous lab use in order to collect analytical and empirical data which will allow further necessary improvements to be incorporated in the design. Year three of the project will give way to the dissemination phase to make the new technology known and accessible to conservators through publications, lectures and training in diverse cultural and geographical milieus.

Expected Results

As a finality, the IMAT project will create a series of innovative and highly accurate mild heating devices, unique in the field, utilizing new materials and new technology based on nanomaterials, to be made available to conservators and scholars in multiple formats: through the presentation of research at conferences, the publication in peer-reviewed journals, the filing of papers on Open Access sites, as well as through a dedicated website (imatproject.eu), workshops and symposia. The project will also involve the manufacture of market-ready IMAT devices which will advance the treatment methodology and will target a very broad audience in the field, essentially all conservators using thermal treatments in one form or another. To implement the use of the new IMAT technology into conservation practice without delay, it will be supported with the new conservation treatment methodology, which will be developed during the project, supported with case studies and published in the final book of the project. The expected results of the IMAT project, with its ambitious multi-faceted aspects of joint effort in interdisciplinary exchange, diffusion of knowledge, and end goal of improving the best practices of conservation of cultural heritage assets, epitomize many broad goals addressed by conservators and conservation scientists today, emphasizing, in particular, the need to continuously address and revaluate the objectives and demands of the field, to integrate contemporary science into the discipline, and to affirm cultural heritage conservation and conservation research as a professional pursuit, fundamental for its role to society.

IMAT background

It must be noted, that although flexible electrically heated mats in general are not entirely new to art conservation, their use was marginal and not developed. For example, in paintings conservation, electrically heated mats (heat blankets) were employed in early heating tables, and Helmut Ruhemann suggested an application similar to ours in 1959 using the Electrothermal Rubber Sheet®. In the same year, Alain Boissonnas described the USKON conductive rubber mat and its use in an early heating table and perhaps similar applications were used by other conservators, but not documented or developed any further. More recently, a silicone heated mat, mounted on a solid support and controlled manually with a dimmer and external thermometer was used by Jos van Och (Stichting Restauratie Atelier Limburg SRAL) in Maastricht for the lining of the colossal Mesdag Panorama mural in The Hague (1990-1996).

First steps towards the pre-IMAT design were taken in 2003, when the first mobile high precision flexible mild heating system was designed and applied successfully by Olsson and Markevicius in the treatment of large scale mural paintings on canvas by H.S. Sewell (1899-1975) in Oregon City, Oregon, USA. The first prototype was made of silicon rubber and wound wire heating elements, connected to a custom designed control unit with an external thermal sensor. Later, a second prototype was created in 2005, with some improvements in its design and was used by Markevicius in his studio in Amsterdam and in the National Gallery of Canada. Both prototypes and later designed heaters have been used since then in the treatment of numerous artworks, which differ in size, period and materials and the results have solicited considerable interest from the conservation community. The simple application, precision, impressive mobility and versatility encouraged further development of the concept of a new mobile mild heating system for art conservation, denominated as IMAT (Intelligent Mobile Multipurpose Accurate Thermo-Electrical). Newly introduced features such as transparency and permeability to gases (airflow and water vapors) were highly desirable. As a result the entire "wish list" was simply unobtainable using traditional materials and in 2009 we started exploring the possibility of replacing the resistance wiring in pre-IMAT design with the relatively new and promising nanomaterials, such as silver nanowires and carbon nanotubes.

Carbon nanotubes: properties and application

Ever since their discovery in 1991 by Sumio Iljima, carbon nanotubes (CNT) have inspired scientists and developers of future technologies, yet, until recently, their practical application was limited by relatively high production costs. CNTs are particularly interesting for various applications in cutting edge electronics, optics and material engineering: they are approximately 50 000 times thinner than a human hair, (i.e. with one gram of CNTs the earth can be circled more than 100 times or makes up three times the distance of earth to the moon), a nd yet they are the strongest and the stiffest materials known, with an E-modulus 10 times greater than steel.

CNTs are molecular scale sheets of graphite (called graphene) rolled up to make a tube and can be described as a new member of carbon allotropes, between fullerenes and graphite. The Single Wall Nanotubes (SWCNT) consist of single graphene rolls, while the Multi Wall Nanotubes (MWCNT) consist of two or more coaxial tubes-within-a-tube. Properties of individual CNTs can be influenced significantly by their chirality (twist) and geometry. Held together by the Van der Waals force, SWCNTs tend to bundle in ropes, while MWCNTs generally form "birds nest" agglomerates due to their growing mechanism in the catalytic chemical vapour deposition process. Both configurations can also be synthesized as "forests" in highly vertically aligned structures (VACNT) for use in electronics.

Perhaps one of the greatest technological potentials of the CNTs at the present time lies in the electrical properties of CNTs to generate heat in a way unattainable with other technologies. The material is not only extremely light and robust, but can also efficiently heat up surfaces of any size, and feature a very rapid thermal response, which is an important factor in maintaining ultra steady temperatures, and in reducing heating and cooling times.

Unlike traditional materials, CNTs conduct electricity balistically, so electrons, just like cars in a multiple lane highway, can be transported in high densities and speed with a minimal resistance and hence the electrical conductivity of CNT along the axis is very high (106 S m^{-2}) and surpasses that of metals, such as copper. They are the best field emitters of any known material and in theory, metallic nanotubes can carry an electric current density of 4 × 109 A/cm^{2} which is more than 1,000 times greater than metals such as copper. CNT thermal conductivity along the axis has been measured as high as 3500 (W m^{-1} K^{-1}), although in theory it could reach 6600 (W m^{-1} K^{-1}). In the direction perpendicular to its axis, however, thermal conduction 100 times or so smaller.

Remarkable electrical and thermal conductivity, unsurpassed mechanical strength and features make CNTs an outstanding material for the IMAT technology and many other innovative applications.

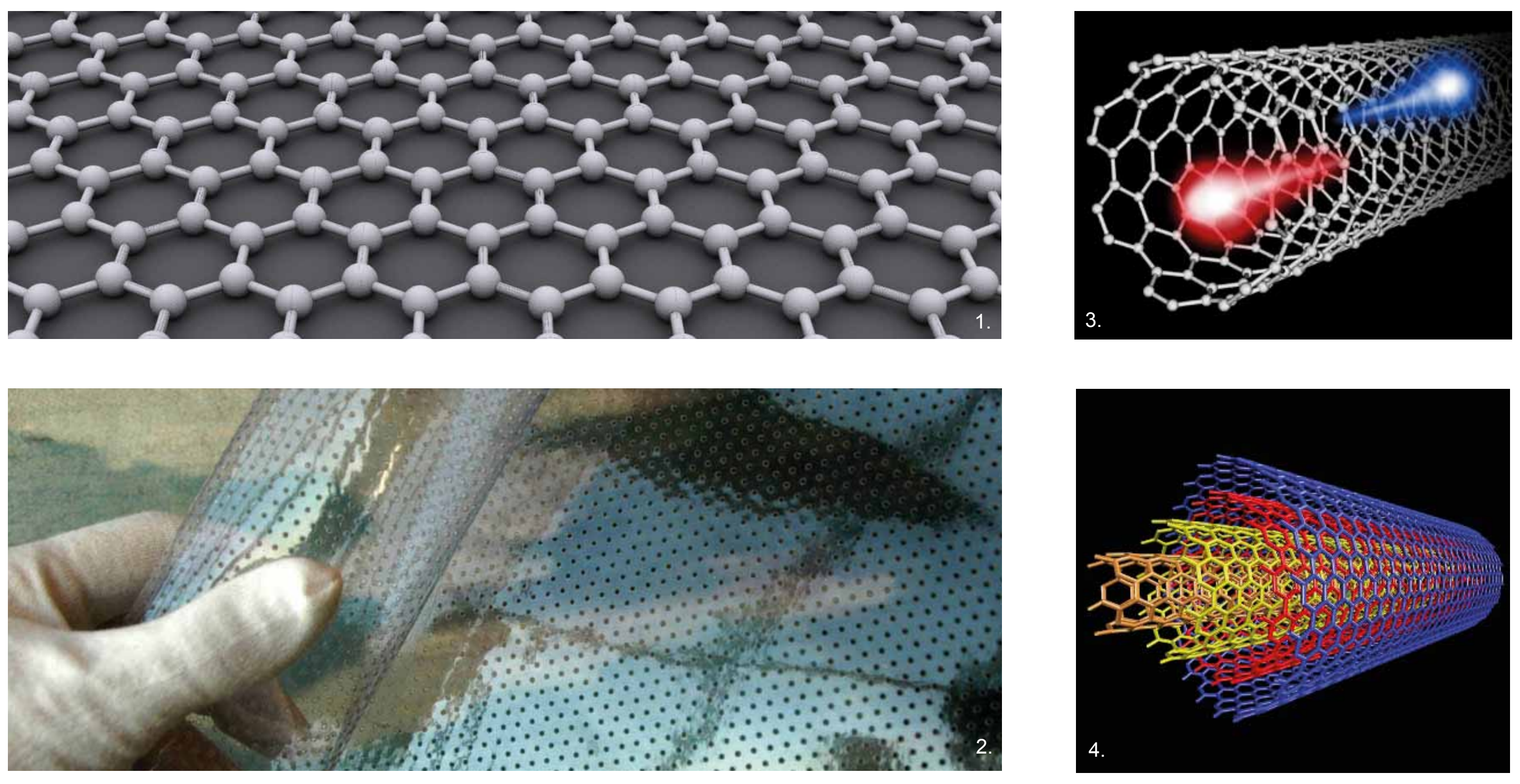
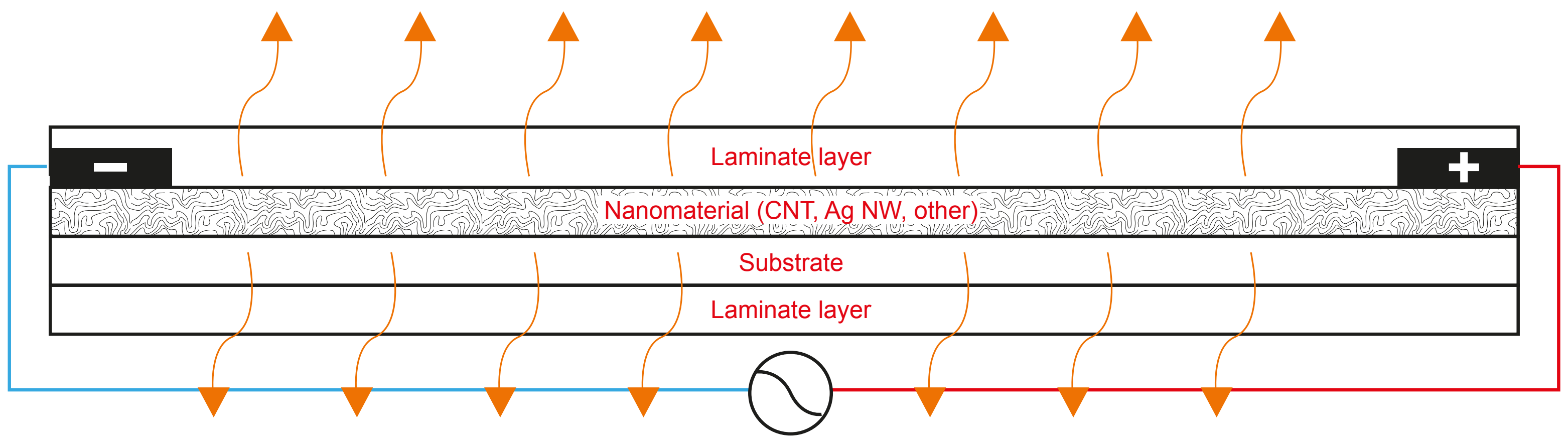


Diagram with graphene layer (1). Conceptual design of transparent breathable (perforated) heater (2). Diagram with single wall carbon nanotube (SWCNT) (3) and multi wall carbon nanotube (MWCNT) (4).

IMAT concept design

The basic design of the IMAT device employs a conductive film heater, made with CNTs or other nanomaterials, and an associated control unit, which includes a series of external controls neatly assembled within a box that also serves as a power outlet for the heater. The IMAT heater is designed with parallel multiple electrodes and when voltage is applied, the current is uniformly distributed over the conductive layer of the deposited nanomaterial and heat is generated.



CNTs, Ag NW or mixture of both with or without the addition of other conductive materials may be deposited on a selected substrate, such as plastic film or an ultra-thin translucent textile, when permeability to gases is desirable. The IMAT heater will have a "sandwich" type structure which, depending on the IMAT, will be composed of two or more layers. In principle, IMAT heater will consist of the heating layer with the CNT film, the electrodes and the temperature sensors and the laminate layer(s), which protect the CNT coating and at the same time and will provide the desirable physical and surface properties to the heater. It is desirable for the IMAT heater to have a soft, non-tack, smooth and lump free surface. The laminate layer is designed to have excellent adhesion to the heating layers as well as excellent resistance to the repeated stress caused by the heating and cooling cycles, and by rolling and other stress related to frequent use. One of the IMAT objectives is to achieve an ultra-low voltage heating (12-24 V). For the low voltage heating, increasing the conductivity of the CNT coating is the main target and we will need to find an optimal formulation of the highly conductive CNT coating in combination with the optimal design of the electrodes. In this research we will work both with the SWCNTS (for transparent heater) and the MWCNTS (for opaque and breathable heaters) in combination with other conductive materials.

IMAT features

1. Portable and mobile
2. Versatile and selective (possibility to apply heat selectively in the desired area)
3. Fast thermal response and highly accurate temperature control
4. Stable temperature
5. Very even heat distribution
6. Transparent or translucent
7. Permeable to gases: airflow, water vapours
8. Soft non-tack surface, resistant to chemicals used in conservation and to physical stress factors related to frequent use
9. Low power needs
10. Safe low voltage reaching 12-24 V and below 100 V
11. Economically accessible

IMAT types and properties

1. IMAT-S or "standard" will be a conductive and highly accurate low voltage mobile heater with a soft and non-tack surface, which will be opaque and non breathable. The IMAT-S is intended for thermal treatments where visibility and breathability are not required. This form can be manufactured in large formats and the operating temperature is 20º-70ºC with the maximum of 85ºC.

2. IMAT-B or "breathable" will be a highly accurate and conductive low voltage heater, which will be opaque and which will be permeable to gases, in particular to airflow and to water vapours. The IMAT-B will be developed combining an air permeable hybrid textile, conductive nanomaterials coating and a membrane impermeable to water, yet permeable to gases (airflow and water vapours). The maximum size will be 60 x 40 cm and the operating temperature will be 20º-45ºC with the maximum of 55ºC.

3. IMAT-T or "transparent" will be a conductive low voltage heater, which will be transparent or translucent, but not breathable or permeable to gases. However, a perforated variation of the IMAT-TP (P – for perforated) may be tested, to attempt making a both transparent and breathable heater. The maximum size will be 60 x 40 cm and the operating temperature is 20º- 45ºC with the maximum of 55ºC.

IMAT application in conservation

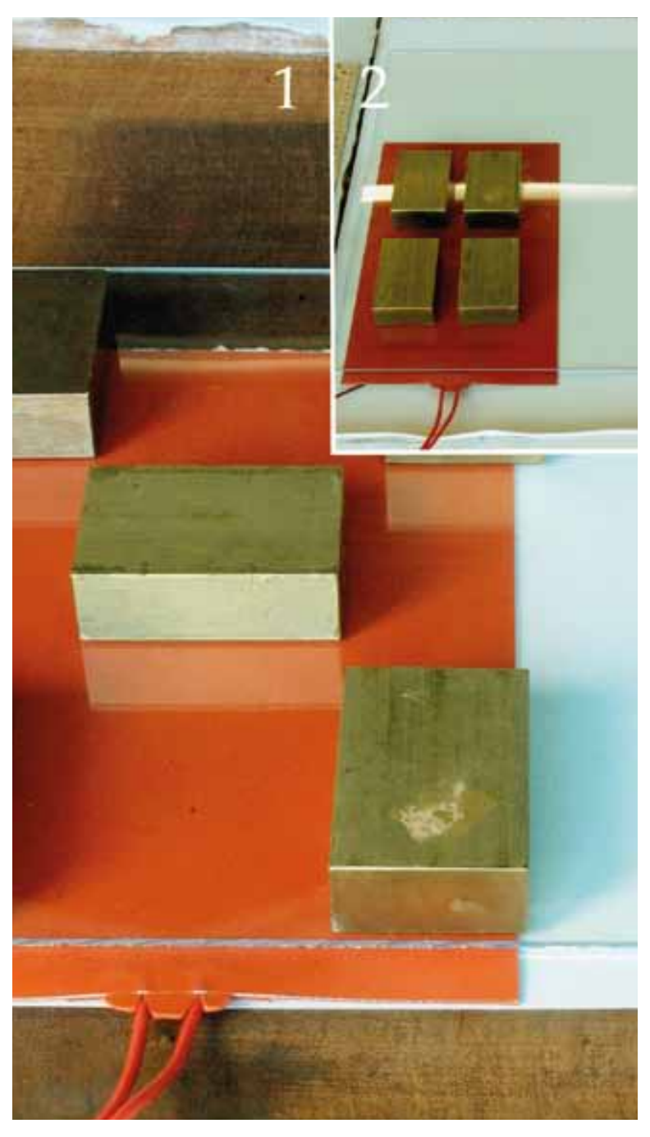
In paintings conservation the new mild heating device (IMAT) may be used in treating diverse deformations and planar distortions, to reduce cupping and distortions to paint film, tear mending, consolidation of paint layers, reinforcement of degraded supports in diverse lining and backing treatments. Air permeability combined with highly accurate and stable mild heating at low temperatures will offer new opportunities for minimal intervention in treating planar distortions, improvement of the condition of earlier treatments, and more. The material of choice needs to exhibit low adherence (a non-tack surface) and high resistance to physical and chemical factors associated with various conservation treatments. The IMAT heater's thin profile, flexible nature and availability in a wide size range are well suited for use in treating works on the stretcher. It may be used with all currently used conservation adhesives and may be incorporated into either traditional or recent methodologies where controlled mild heating is required. Optical properties, such as transparency, would be highly desirable for visual control during treatment, especially when the heat source is applied to the recto. IMAT could find its application also in aesthetic treatments, such cleaning of painted surfaces with enzymes, which require very precise and specific temperatures of application, and which must stay constant during the treatment. The IMAT would be particularly useful for in situ work, and in emergency response actions.

In paper conservation the IMAT could be used in treating planar distortions and in consolidation treatments, where mild heating is required. The combination of highly accurate temperature control and permeability to gases, such as airflow and water vapours, as well as transparency would be a strong asset in many humidification treatments. As in paintings conservation, the new heating device will find its application in enzymatic cleaning treatments, which are frequent in paper conservation. Yet another application could be thermal disinfection treatments.

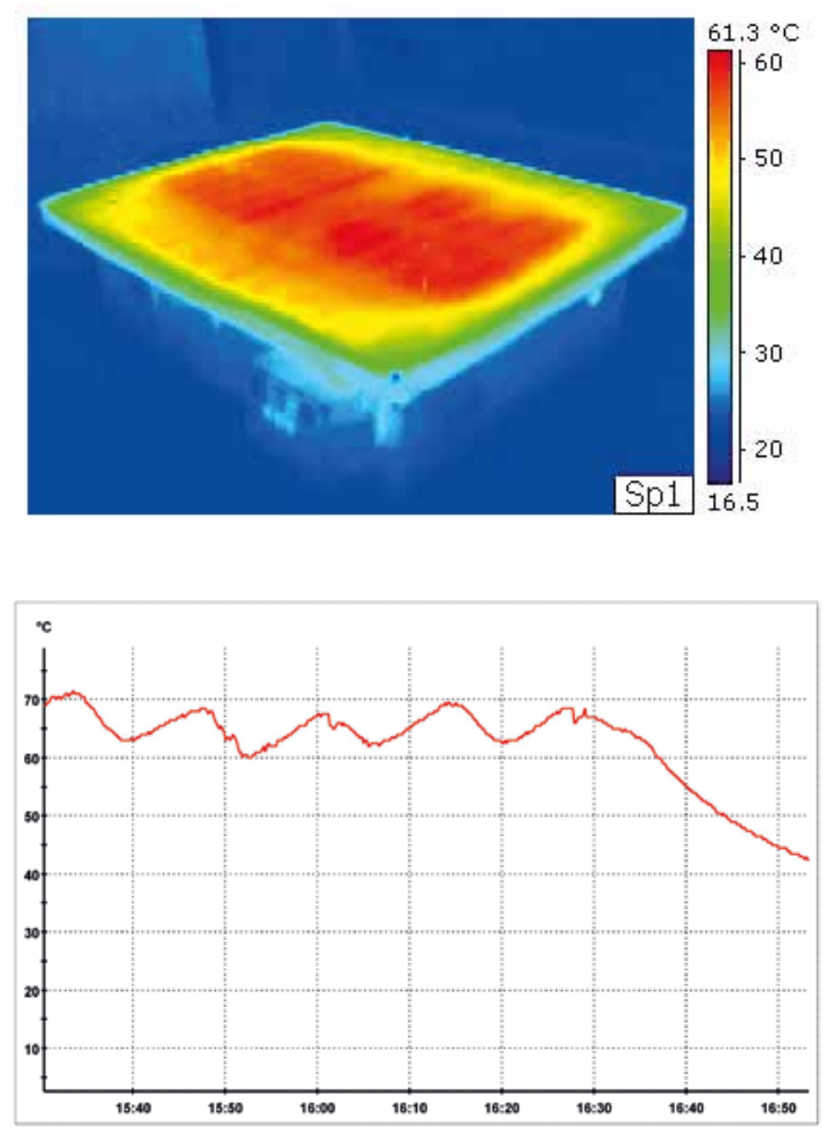
In textile conservation the IMAT could be applied in methods similar to those implemented in painting or paper treatments, used for consolidation, smoothing planar distortions, using enzymatic methods of cleaning and more. An added advantage of the device would be the option of placing the heat source simultaneously on both sides or on either side, as well as performing the work in sections on large pieces. Yet another application could be thermal disinfection treatments.

In 3-D objects and other applications IMAT heaters of diverse configuration and shape could be applied in consolidation treatments. These could be quite useful for polychrome sculptures, frames, furniture, mixed media objects and more.

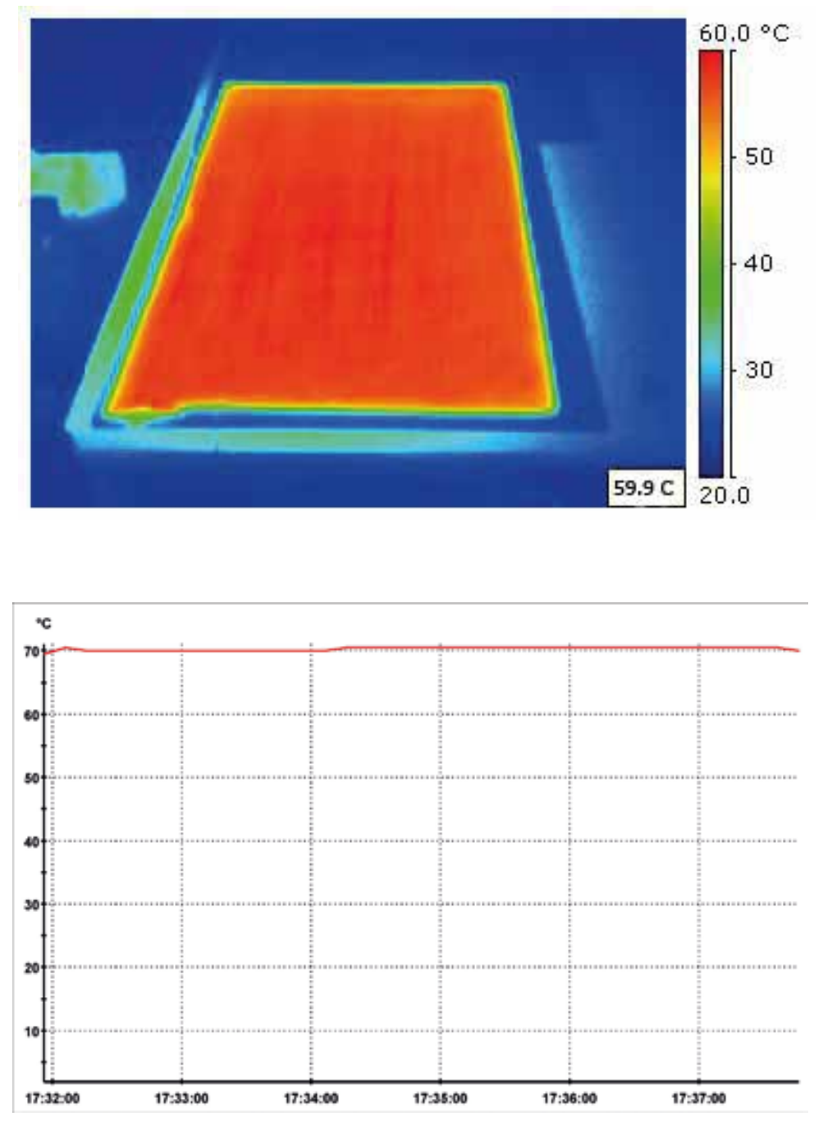
In other applications the availability of this new mild heating technology and the programmed field testing will allow conservators to find additional applications and ways of incorporating its use into both current treatments, and new methodologies that have yet to be developed. For example, developing and advancing other conservation tools where mild heating is required, such as heated syringes, heated spatulas, soft heated tips and other.



Application of experimental pre - IMAT mild heater in humidity treatment flattening surface deformations.



Thermographic image of a 1990's multipurpose low pressure heating table in current use, showing uneven heat distribution, and graphic of surface temperature fluctuation.



Olsson-Markevicius experimental mild heater: thermographic image and graphic showing steady temperature during the treatment.

IMAT Partners:
Università degli Studi di Firenze (Italy) - coordinator, Nardini Press S.r.l. (Italy), Future Carbon GMBH (Germany), C.T.S. S.r.l. (Italy), Amorosi Laura Studio (Italy), Sefar AG (Switzerland), Lorenzo Conti Studio (Italy), Istituto per l'Arte e il Restauro Palazzo Spinelli, Istituto per l'Arte e il Restauro (Italy), Tomas Markevicius and Nina Olsson (Lithuania), Lietuvos Dailes Muziejus (Lithuania)