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IMAT Project: From Innovative Nanotechnology to Best Practices in Art Conservation

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Abstract. The research and development of new conservation materials and instrumentation and the integration of contemporary science into the discipline are of fundamental importance in formulating best practices in conservation and preserving cultural heritage assets. With this goal in mind in November 2011, the IMAT project (Intelligent Mobile Accurate Thermo-Electrical mild heating device) was launched under the European Commission's 7th Framework Program (FP7) for research. During the three-year length of the project, coordinated by the University of Florence, a European consortium of researchers representing expertise in conservation, nanotechnology, and thermo-electrical engineering will develop nanotechnology for the IMAT devices specifically designed for highly accurate mild heating in conservation of artworks and other cultural heritage assets.

Keywords: IMAT, nanotubes, mild heating, conservation.

1 Introduction and Partners

Sophisticated and accurate instrumentation allows conservators to treat artworks within the margins of minimal intervention and risk, while achieving the maximum result. The IMAT project responds to a critical omission in current treatment instrumentation for accurate, selective and mobile devices for mild heating, which is essential for success in most structural treatments of paintings, works on paper, textiles and other cultural heritage assets [1]. The IMAT project researches the application of carbon nanotubes and other conductive nano-materials to design new highly accurate mobile technology and devices - in the form of flexible mat heaters – "imats" with the unique qualities for conservation (see Figure 1). The IMAT project involves cross-discipline team of scientists, electrical engineers and conservators working alongside from the initial concept design phase throughout the final stages of testing and dissemination so as to gain the best insight into design improvements, to optimize the range of potential applications and to develop new treatment

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methodology. Università degli Studi di Firenze (UNIFI, Italy) is the coordinator of the project, which is lead by Tomas Markevicius and Nina Olsson (Lithuania). UNIFI will also develop the console and temperature controls for the new device. Future Carbon GMBH (Germany) is responsible for the development of the innovative nano-coating, which is carried out in close collaboration with the Sefar AG (Switzerland) and the UNIFI. Stichting Restauratie Atelier Limburg SRAL (the Netherlands), Laura Amorosi (Italy), Lorenzo Conti (Italy), Lietuvos Dailės Muziejus (Lithuania) and Istituto per l'Arte e il Restauro Palazzo Spinelli (Italy) are responsible for the field testing of the IMAT techonolgy, while Nardini Press S.r.l. (Italy) will contribute in the dissemination and C.T.S. S.r.l. (Italy) in marketing making available the device available for the conservators.

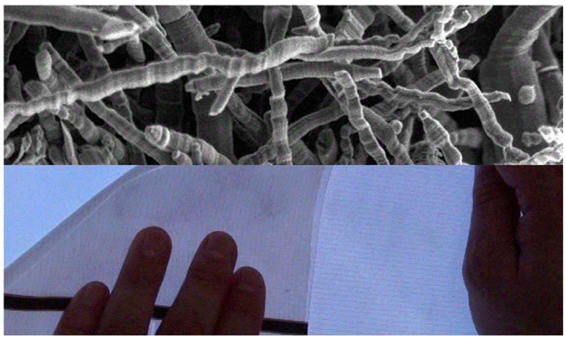

Fig. 1. SEM image of carbon nanotubes and transparent heater with the hybrid textile by Sefar AG

2 Brief State of Art and Background

Although flexible electrically heated mats in general are not entirely new to art conservation, their use was marginal and virtually undeveloped. 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® [2]. In the same year, Alain Boissonnas [3] 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 prototypes were taken in 2003, when the first mobile high precision flexible mild heating system was designed and applied successfully by N. Olsson and T. Markevicius (see Figure 2) in the treatment of large scale mural paintings on canvas by H.S. Sewell (1899-1975) in Oregon City, Oregon, USA [4].

This and later designed prototype precision flexible heaters have been used since then in the treatment of diverse artworks and the results have solicited considerable interest from the conservation community. The need for the new mobile highly accurate and versatile mild heating device encouraged further development of the concept design of a new mild heating system for art conservation, denominated as IMAT (Intelligent Mobile Multipurpose Accurate Thermo-Electrical). Because of newly introduced features of the concept design, such as low voltage heating, transparency and permeability to gases (airflow and water vapours), the entire “wish list” was simply unobtainable using traditional materials, but possible through the use of promising and cutting edge highly conductive nanomaterials, such as silver nanowires (AgNW) and carbon nanotubes (CNT). 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 [5].

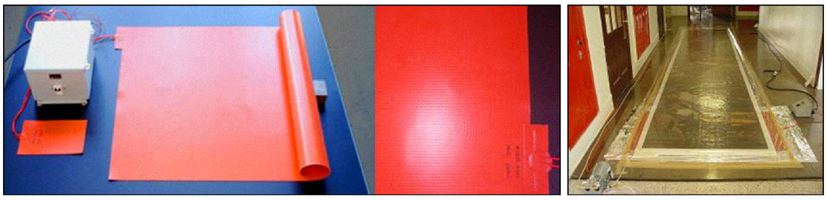

Fig. 2. Experimental Olsson-Markevicius silicone rubber and wound wire mild heater (2005) and lining one of the H.S Sewell murals using vacuum envelope and flexible thermal blanket. Portland (OR) USA 2003 (right)

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 (see Figure 3). 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, and yet they are the strongest and the stiffest materials known to man, with an E-modulus 10 times greater than steel [6]. 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. While the thermal conductivity of CNTs along their axis is high, and has been measured as high as 3500 (W m^{-1} K^{-1}) (although in theory it could reach 6600 (W m^{-1} K^{-1})), the thermal conduction is 100 times or so smaller in the direction perpendicular to its axis. The overall conductivity is an average sum of the two. The remarkable electrical and thermal conductivity and unsurpassed mechanical strength make CNTs an outstanding material for the emerging IMAT technology [7].

3 Methodology

The IMAT project was conceived with a research-based objective and with a bottom-up design format, unique in the field, to be mirrored in the development of the associated treatment 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. The work on the prototypes will continue in the second year, when the field testing partners - conservators and conservation education and research institutions - will submit the prototype designs to rigorous lab use in order to collect analytical and empirical data which will allow further improvements to be incorporated in the design. Work prototypes will continue in the year three, when the project will also 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.

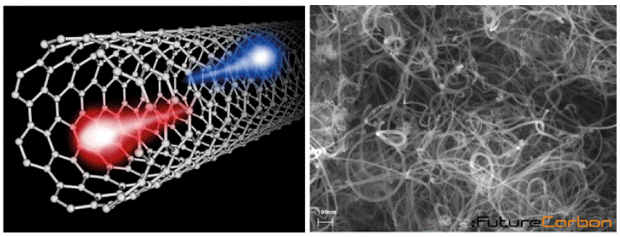

Fig. 3. A diagram showing the types of single wall carbon nanotube (SWCNT) (left), SEM image of carbon nanotubes bundles and a diagram with a multi wall carbon nanotube (MWCNT) (right), (Michael Ströck, Wikimedia images)

3.1 Progress So Far

Perhaps one of the greatest technological potential of the CNTs and other conductive nanomaterials (graphene, silver nanowires AgNW) at the present time lies in the electrical properties of CNTs and other nanomaterials to generate heat in a way unattainable with other technologies. The CNT material can very efficiently heat up surfaces of any size and shape, and feature a very rapid thermal response, which is an important factor in maintaining ultra-steady temperatures and in reducing heating and cooling times. In the initial R&D phase, the IMAT team has been working on establishing the technical and operational parameters and defining the conceptual design of the IMAT device as well advancing and developing the nanomaterial-based coating that could meet the particularly high requirements for the thermal and electrical conductivity required for the IMAT. The basic design of the IMAT device employs a conductive film heater, made with CNTs or other nanomaterials, and an associated control unit (console) that also serves as a power outlet for the heater. The

IMAT heater is designed with multiple parallel electrodes (see Figure 4) and when voltage is applied, the current is uniformly distributed over the conductive layer of the deposited nanomaterials and heat is generated [8, 9].

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, consisting of the CNT-film heating layer in the center with the electrodes and temperature sensors, protected by exterior laminate layers, which will also provide advantageous physical and surface properties to the heater.

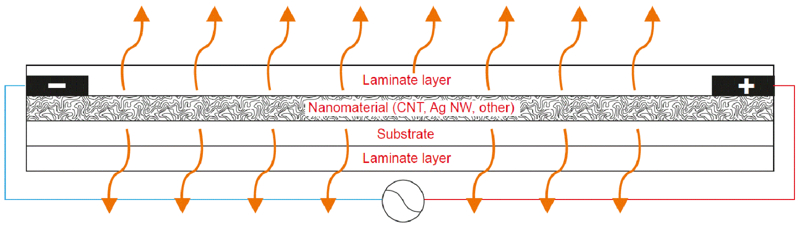

Fig. 4. Schematic drawing of IMAT heater

It is desirable for the IMAT heater to have soft, non-tack, ideally smooth and texture-free surface. One of the IMAT objectives is to achieve reduced voltage heating (12-24 V). For low voltage heating, the main targets will be to increase the conductivity of the CNT coating and 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. More technical challenges will be represented by the introduction of the electrodes and temperature micro-sensors, by the optimization of the adhesion between the nanomaterial layers and the laminate, by the design of the control unit interface and more, which will all require extraordinary engineering solutions.

3.2 IMAT Features and Prospective Uses in Conservation

IMAT offers to conservators new technology and devices with the radically new technical characteristics. The major IMAT features are as following:

- Portable, mobile, versatile and selective (possibility to apply heat selectively in the desired area).
- Fast thermal response and highly accurate temperature control and stable temperature.
- Very even heat distribution, transparent or translucent.
- Permeable to gases: airflow, water vapours.

- Soft non-tack surface, resistant to chemicals used in conservation and to physical stress factors related to frequent use.
- Low power needs, safe low voltage reaching 12-24 V and below 100 V.
- Economically accessible.

To further improve the performance of the IMAT, it will be designed in three different types, which will reflect the needs of specific applications in conservation.

1**. IMAT-S or "standard"** will be conductive highly accurate low voltage mobile heater with soft and non-tack surface, which will be opaque and non breathable. The IMAT-S is intended for the thermal treatments where visibility and breathability are not required. 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 highly accurate conductive low voltage heater, which will be opaque and permeable to gases, in particular to airflow and to water vapours. The IMAT-B will be designed by combining an air permeable hybrid textile, a conductive nanomaterials coating, and a gas permeable membrane (airflow and water vapours) that is impermeable to water. 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 conductive low voltage heater, which will be transparent or translucent, but not breathable or permeable to gases. However, a perforated variation, the **IMAT-TP** (P – for perforated, see Figure 5)) may be tested, in an attempt to make a heater that is both transparent and breathable. The maximum size will be 60 x 40 cm and the operating temperature is 20º- 45ºC with the maximum of 55ºC.

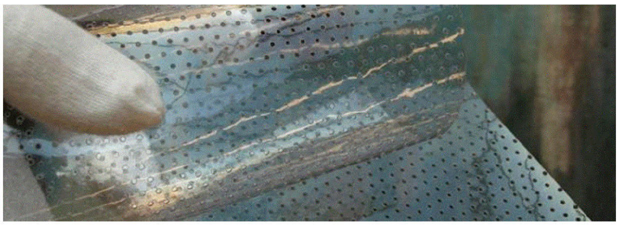

Fig. 5. Conceptual design of IMAT TP

In Paintings Conservation. 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 (see Figure 6), 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 more 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 (see Figure 7), 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.

Fig. 6. The IMAT heater's thin profile allows it to be easily inserted under the stretcher or "sandwiched" with other materials used in diverse structural treatment

Fig. 7. IMAT would be most useful in all structural treatments, where accurate mild heating is one of most often used means of treatment

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 air flow 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.

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. 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.

4 Conclusions

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, publications, as well as through a dedicated website (imatproject.eu), workshops and symposia. The project will also involve the manufacture of market-ready IMAT devices to implement the use of the new IMAT technology into conservation practice without delay. The device 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, and to affirm cultural heritage conservation and conservation research as a professional pursuit, fundamental for its role to society.

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