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PAINTINGS

New approaches to an old problem: A precision mild heat-transfer method for the nuanced treatment of contemporary and modern art works

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INTRODUCTION

When heat is applied to any substance, the transfer of energy determines the state, behavior and performance of the substance. Heat transfer is a powerful tool in conservation treatments, yet it cannot be fully exploited without due control. In fact, the risk to an artwork increases as the precision of heat transfer decreases. This is particularly relevant for fragile modern and contemporary materials, which require mild heat transfer (± 25°C–40°C). Structural treatments combining pressure, heat, moisture, and adhesives may radically alter the paint surface. Historically, the crude heating tools or procedures used by restorers resulted in uncontrolled heat, pressure and moisture and thus unpredictable outcomes. The evolution of heating instruments reflects the attempt to gain control over heat transfer: flat irons eventually became thermostatically controlled electrical appliances; the use of heated sand or hot-water bags was superseded by incandescent or infrared lamps and hot tables, which in the late 1940s were replaced by veneer presses for wax-resin lining (Ruhemann 1953). In the 1980s, hot tables were further adapted into multipurpose tables that combined heating, humidification, and low-pressure functions (Reeve 1984).

The threat of an unwanted physical impact has long been acknowledged, but only recently have surface changes caused by treatments been systematically visualized or quantified. These analyses were facilitated by advanced imaging techniques and precision instrumentation such as stereomicroscopy, atomic force microscopy, scanning electron microscopy, and 3D Hirox microscopy. The insights obtained heightened awareness on the part of conservators, who updated their philosophy, approaches and methodologies. Yet, the instrumentation used for heating remains problematic. By and large, heat-transfer methods have not evolved since the 1980s and still rely on rudimentary devices that have proven inadequate to deliver a mild amount of heat evenly and accurately over larger areas as well as onto textured and 3D surfaces. Typical instruments, even if thermostatically controlled, have wildly fluctuating temperature cycles that correspond only “on average” to the temperature desired. These instruments are usually regulated only at temperatures over 40°C, making mild temperature ranges inaccessible. Moreover, conservators lack portable instrumentation for heat transfer over large surfaces, and economically unsustainable hot tables are notorious for “hot” or “cold” spots, which impair effective treatment and threaten

KEYWORDS: mild heat transfer, paintings, nanomaterials, temperature, enzymes

ABSTRACT

When treating sensitive modern and contemporary artwork materials, the degree of accuracy and the steadiness of heat transfer are essential in achieving the effective and safe consolidation of the paint, treating planar deformations and cupped cracks, and in the use of lining, enzymatic cleaning and other treatments. Most of the various heating instruments commonly employed today were developed for non-conservation uses and, lamentably, lack precise controls and an even heat distribution. These deficits limit the utility of these instruments and the degree of conservation success.

This paper describes an innovation in both the design and methodology of heat transfer, using both flexible mats and e-textile mats made with nanomaterials. Both result in highly accurate and steady mild heat transfer. Flexible mild heating mats have been applied in a series of treatments since 2003. Multiple advances have since been made in their design and the protocols have been refined. Recent developments in nanomaterials have radically expanded the technical capabilities of heated mats, resulting in safer and more nuanced treatments.

the safety of the artwork. Moreover, the high voltage requirements make these large units infeasible to use on site. How can conservators refine treatments using such blunt instruments?

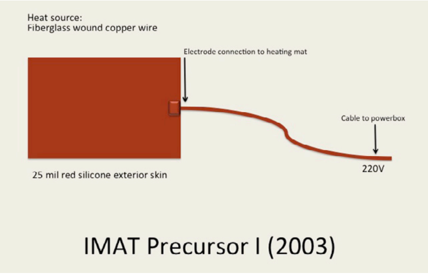
ACCURATE MILD HEAT (AMH) TRANSFER WITH NANOTECHNOLOGY

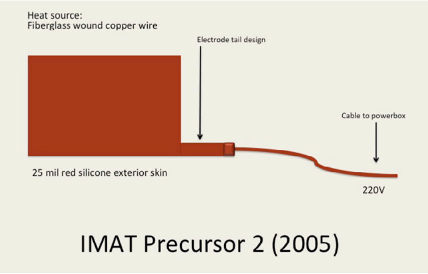
Conservation treatment capabilities are being expanded and refined by the recent availability of AMH sources. Among the techniques being explored are flexible mats with features such as transparency, breathability, and the ability to conform to textured 3D surfaces. Equipped with advanced sensing and controls, the "smart" mats provide even and steady heat transfer in the mild temperature range (<40°C). An additional advantage is that they can be rolled up and transported to a work site, or stored when not in use. The size of the mat may be customized, but typical dimensions necessitate treating larger paintings in sections.

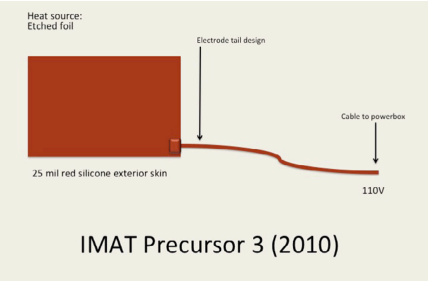
While flexible heaters are broadly applied in the aerospace and life sciences, they have had limited use in conservation practice. A flexible mat design was first proposed by Ruhemann in the 1960s, but it was not developed. The colossal Panorama Mesdag (1881) in The Hague was lined in the 1990s with a perforated silicone rubber mat designed and built as a rigid heating platen by Jos van Och (SRAL). Nina Olsson and Tomas Markevicius used the first flexible heating mat prototype in 2003 to treat two murals on canvas (1937) by H.S. Sewell. The same methodology has since been further applied in many other treatments, including the lining of a 17th-century painting by Willem van Aelst (1654) and, in 2010, for the lining of the upper fragment of Veronese's Petrobelli altarpiece (1565) (Olsson and Markevicius 2010).

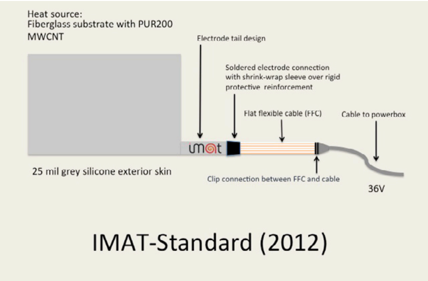
The methodological advantages realized in these early applications encouraged the pursuit of additional features to compliment the accuracy and versatility of the new portable heat-transfer system. Both transparency and permeability to airflow and water vapor were desirable, since humidity is often used in conjunction with heat transfer. However, technologies based on wound wire or etched foil heating precluded advances beyond the industrial status quo. The solution was found in electrically conductive nanomaterials, including carbon nanotubes (CNT) or silver nanowires, which could be exploited to realize transparent and permeable heating mats. Nanocoatings can be applied to air-permeable textiles or yield transparent coatings that efficiently heat up surfaces of any size. Their very rapid thermal response is an important factor in maintaining steady warming. Innovation of the new heat-transfer system became the main focus of the European IMAT project,[1] during which CNT heating mats were designed and created in ultra-thin profiles with non-tack surfaces, in transparent and permeable forms, using electronic textiles woven with CNT yarns (Table 1). The project also resulted in the design of a novel heat sensing, control and monitoring system that provides even heating with an accuracy of 0.1°C (Figure 1). In contrast to heating tables, which require power up to 350 V, IMAT operates at 36 V, which is safe to the operator (as it cannot pass the human skin barrier) and falls under the EU Ultra Low Voltage (ULV) Regulations. ULV makes the IMAT an ideal multiuse portable instrument

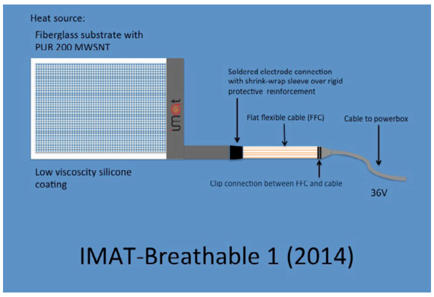
Table 1. A selection of the IMAT prototypes

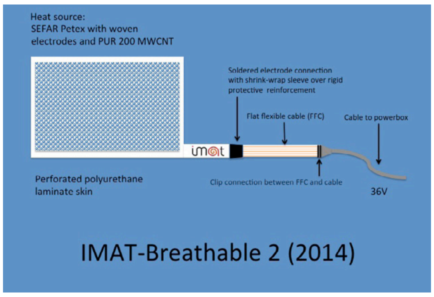


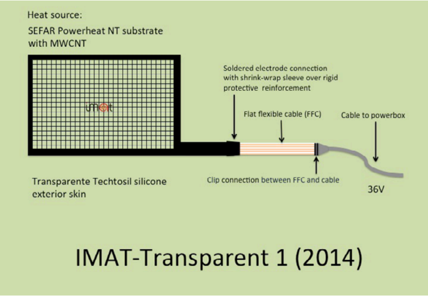


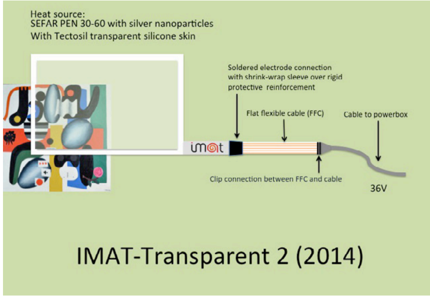












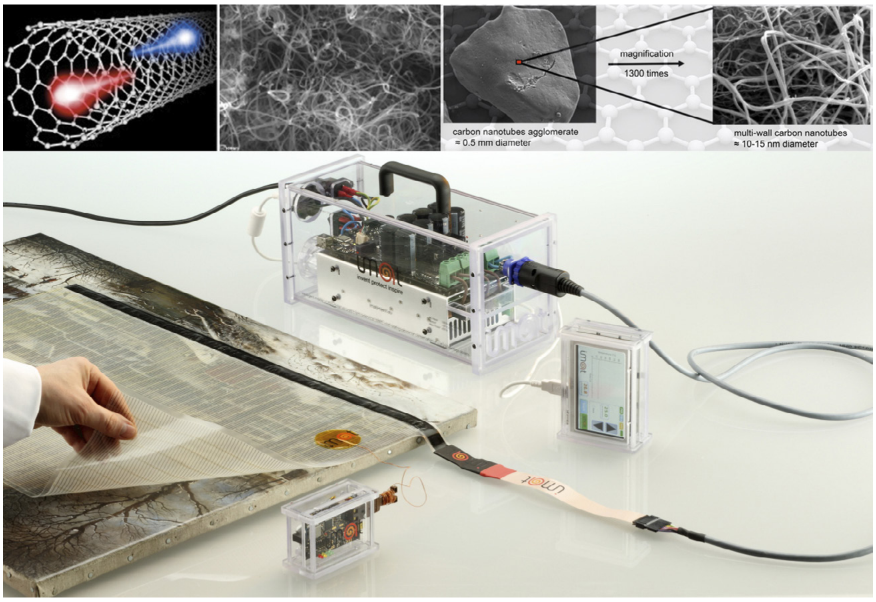


Figure 1. IMAT prototype. Schematic view of a carbon nanotube and transmission and scanning microscopy images of nanotube agglomerates

for field and laboratory work, in emergency response conditions, and for work in locations with a limited power supply.

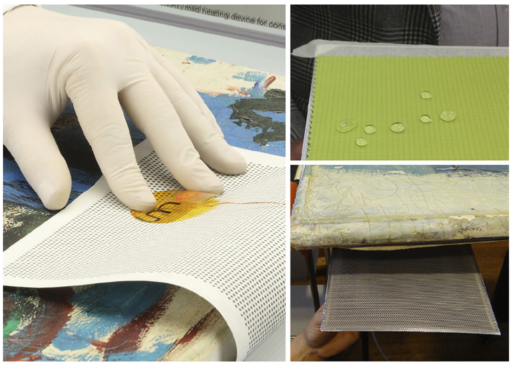
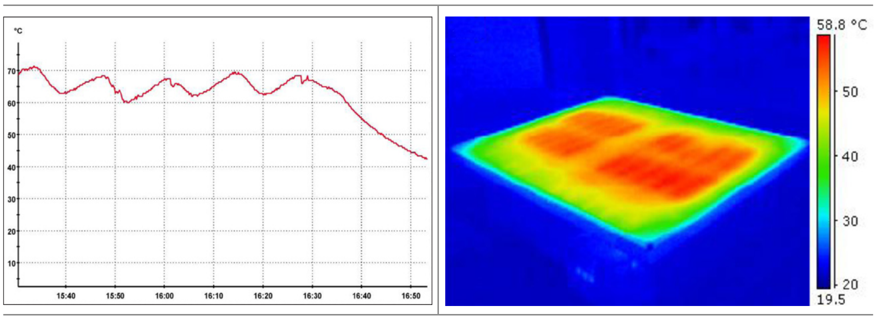


Figure 2. A breathable heating mat (left) is combined with mini suction platen (bottom right) and a microporous membrane (top right)

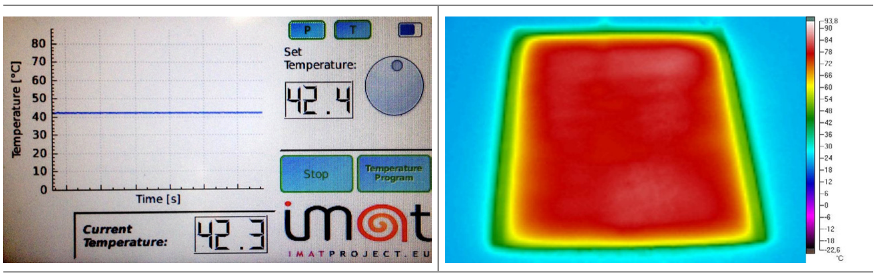
TOWARDS A NEW TREATMENT METHODOLOGY

Until recently, a technology that permits steady AMH transfer had eluded the field of conservation (Table 2). The testing of both flexible heating mats and IMAT prototypes is ongoing, and their full potential is still to be discovered. The maintenance of constant heat transfer over a low temperature range (20–40°C) allows conservators to lengthen the application times and therefore to deliver heat such that it gradually and uniformly permeates the entire paint, ground, and canvas structure. Extending the application times has proven to be crucial since it allows rigid, thick structures to become pliable without causing extreme temperature differentials between the surface and the interior. Because of the mat's thin profile, it can be inserted between the canvas verso and the wood secondary support, such that conservators can perform minimally invasive treatments with the painting on the stretcher. Air permeability combined with AMH offers new opportunities in treating planar distortions, the conservation of earlier treatments, etc. (Figure 2). AMH was also shown to enhance enzymatic activity in cleaning. The following case studies involving modern and contemporary paintings describe the improved treatments achieved with the aid of new AMH transfer technology refined with nanomaterials.

Table 2. Comparison of the heat fluctuation and distribution in a multipurpose heating table from the 1990s vs. IMAT



Multipurpose heating table: Temperature fluctuation and thermography showing an uneven heat distribution



IMAT: Steady temperature fluctuation and thermography showing an even heat distribution

TREATMENTS

Treating planar deformation on the stretcher

In Louis Bunce's *Cliffside* (1952–53) (oil on linen, 115.6 × 82 cm, Portland Art Museum, Portland, Oregon), the original mounting by the artist onto a homemade wood strainer was conserved. Surface distortions had formed due to a lack of uniform tension and the under-use of securing tacks, which resulted in structural threats to the condition of the work: scalloped and puckered surface distortions, buckling, stress fractures to the paint and ground layers, slackening of the canvas, and the formation of cracks from contact with the strainer. The scope of the planned treatment was to reduce or eliminate surface deformations without removing the painting from its original stretcher. Once the paint and ground layers were stabilized, a localized method was used to achieve uniform tension and planarity: strips of organza were prepared with BEVA-film and cut ad-hoc to a length allowing them to be introduced between tacks. The fine textile strips were inserted between the strainer and the tacking edge where puckering was present or where the distance between tacks was excessive. The organza tabs were then adhered to the tacking edge verso by means of heat activation (65°C). Planar deformations were humidified and AMH (40°C) was applied to the recto. As the deformations relaxed, the attached organza tabs were gradually pulled and secured to the wood strainer with additional tacks.

Figure 3. Treatment of Frank van Hemert's *Initiatie* (1992–93): breathable IMAT and suction platen were applied from the verso while conservator J. Bierings treats the cupped delamination from the front

Treating surface deformations and high, raised cupping

Treatment of Frank van Hemert's *Initiatie* (1992–93) (oil on canvas 270 × 128.7 cm, Schunck in Heerlen, Netherlands) was aimed at consolidating the pronounced and lifted cracks and treating the planar deformations in the paint film. The application of mild heat using IMAT allowed the modern oil paint to relax gradually and at 35–40°C activated the adhesive used for the consolidation. Low pressure was applied from the back to improve the penetration of the consolidant (Aquazol 50:200:500/1:1:1 volume) and to keep the deformed paint in a flat position. The vertically mounted suction platen and IMAT permitted the localized consolidation to be conducted vertically, which was required because of the size of the painting (Figure 3).

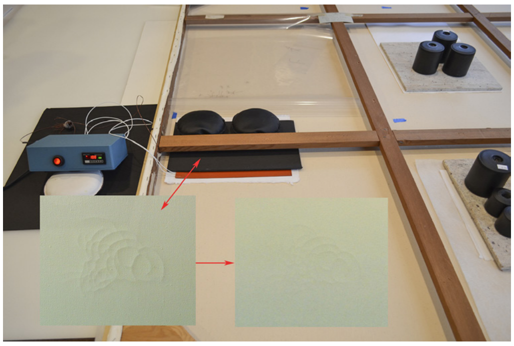


Figure 4. Michael Dailey's *Spring Beach* (1968): accurate mild heat (AMH) applied with a mat in combination with pressure for the local treatment of cupped cracks. A detail of the cupped cracks BT and AT

A color-field painting by Michael Dailey, *Spring Beach* (1968) (oil on cotton canvas, 178.5 × 174 cm, private collection, Portland, Oregon, USA), was marred by 23 crack patterns, with pronounced cupping in the thick oil paint layer, that were particularly disfiguring. The cracks were identified with raking light and mapped onto a transparent film (Gridley 2014). To smooth the cupped cracks, humidity was applied locally via moistened blotters to the verso at the crack sites, followed by AMH (38°C–43°C) applied locally. Through testing it was determined that the mild, steady, and sustained heat transfer was the critical element in the successful smoothing of the cupped paint film. Heat was ultimately applied for 30–40 minutes to relax the cotton duck canvas and soften the paint layers to smooth the deformations. After smoothing, the most severely cupped sites were reinforced by the application of gelatin, to size the canvas verso in correspondence with the crack pattern, and subsequently heated and then dried with blotters under heavy weight (Figure 4).

Treating planar deformations of BEVA 371 lined paintings

Robert Motherwell's *Open No.16 in Ultramarine with Charcoal Line* (1968) (acrylic on canvas, 252.7 × 473.7 cm, ex. collection Dedalus Foundation) was damaged during transport, leaving a 13-cm concave, dimpled dent in the center of the composition and two areas of surface distortions in the lower corners. The work had been previously cold-lined with BEVA-gel onto cotton canvas. Due to the large format and fragile transport status of the work, treatment was conducted at a storage facility, with the painting mounted vertically to provide access to both faces. A thin-profile heating mat (22 × 28 cm) was introduced between the wood stretcher and the canvas and heated to 40°C for 10 minutes to soften the lining adhesive and relax the canvas and paint layers. Once softened and smoothed, the deformation sites were cooled between two heat sink plates held in place for 30 seconds from either side. The same procedure was used to smooth the concave dent in the center. Various features of the heating mat system were ideal in resolving the challenges involved in this specific case: 1) the portability of the system allowed the work to be conducted on site; 2) the size of the heating mat allowed the heating of an area slightly larger than the dent sites; 3) the thin profile of the heat-transfer mat promoted heat transfer to the verso, which was otherwise inaccessible due to the stretcher; and 4) the accurately maintained low temperature was ideal in treating the acrylic paint film within the safest range (Figure 5).

Figure 5. Robert Motherwell's *Open No.16 in Ultramarine with Charcoal Line* (1968): AMH is applied with a mat from the verso to treat planar deformations

Lining, consolidation, treating planar deformations

Treatment of Howard S. Sewell's *The Coming of the White Man,* and *Immigration* (both 1937) (both oil on cotton, 153 × 690 cm, Oregon City High School, Oregon City, USA) exemplifies how a portable flexible AMH source allows the on-site treatment of large-format paintings. In 2003, a prototype heater was custom designed for use in the treatment of these two New Deal mural paintings on canvas that required relocation. The silicone rubber heating mat with wound wire elements was custom-made to a size of 91 × 168 cm to accommodate the height of the paintings, each composed of three separate sections, originally marouflaged to the wall as a single image. The works were lined onto a single continuous needled-felt backing with a Reemay interleaf loaded with BEVA 371. A vacuum envelope was created with Dartek with two outflow points connected to a GAST-0523 vacuum pump. The works were then heat-bonded in sections to the backing, positioning the thermocouple between the heater and the backing surface. The heating mat allowed the work to be conducted on site at the school using a 240 V circuit (Figure 6).

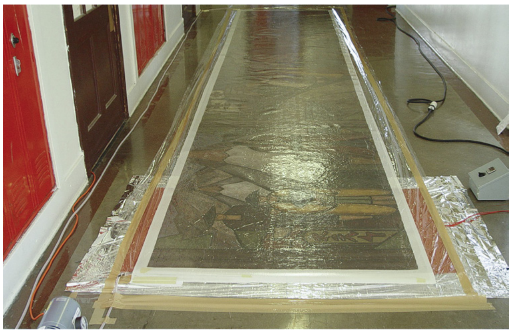


Figure 6. Howard S. Sewell's *The Coming of the White Man* (1937): during treatment, a low-pressure envelope and AMH were applied with flexible mat for lining

AMH was indispensable for the treatment of Kenneth Hudson's *Allegory of State of Oregon and the University of Oregon* (1928) (oil on canvas, 117 × 203 cm, Straub Hall, University of Oregon, Eugene, USA). The mural was originally tacked directly onto the masonry wall, where it was exposed to condensation that caused severe planar deformations of the canvas. The lunette was tensioned onto a provisional strainer with muslin strips adhered to the edge with BEVA-film, and the entire canvas verso was humidified for 1 hour. As the stiff, hardened canvas became supple, the tension of the canvas was adjusted to target and improve planarity in the most distorted areas. AMH was applied to the recto beginning at 22°C and incrementally raised to 40°C over a period of 15 minutes, then maintained at 40°C for 45 minutes until it was dry, with the periodic substitution of blotters to absorb the introduced humidity. The use of low-temperature AMH, introduced gradually and maintained over an extended period, led to the successful elimination of all surface distortions (Figure 7).

The mural was housed in an architectural niche, located in the entrance foyer of a high-traffic public building lacking stable ambient conditions. Dibond, an aluminum-clad composite panel with a polyethylene core, was chosen for the backing material because it provides a self-supporting thin profile, thermal and vapor insulation, and custom cutting in a cost-effective manner. Once the panel was cut to shape, a Reemay interleaf was adhered onto the panel with BEVA 371. An additional layer of BEVA film was cut and thermally adhered to the lining interface within a vacuum envelope. After preparation of the backing panel, the painting was removed from the provisional strainer, positioned onto a panel, and nap-bonded within a low-pressure envelope at the 65°C activation temperature using a flexible heater.

Figure 7. Kenneth Hudson's *Allegory of State of Oregon* (1928): planar deformations (top left), tensioning with strips (bottom left), treatment of the planar deformation with AMH (bottom right), AT after lining (top right)

Deformation in paintings treated with wax

Wax-resin was widely used for structural treatments until the 1972 Greenwich conference findings and beyond. Numerous modern painting have been preventively infused and/or lined with wax, such as the uniform treatment of works by van Gogh or the many paintings treated with wax 40 or more years ago, such as Picasso's *L'atelier* (1928) (Peggy Guggenheim Collection, Venice), or Magritte's *L'assassin menacé* (1927) (MoMA, NY). When paintings with this treatment history require consolidation or the repair of planar deformations, intervention is problematic without an AMH source, due to the thermal sensitivity and melting behavior of crystalline waxes, whose temperature range for safe treatment is just above room temperature, with a critical upper limit at or below 40°C. The lack of adequate low-temperature devices has frequently led to the invasive removal of wax-resin linings. Testing of AMH on wax-treated paintings is nascent and has been limited to simulated treatment (Figure 9). Preliminary results indicate that gradual AMH over an extended period of time allows the safe and effective treatment of deformations and dents and the reactivation of wax-based adhesives. The authors look forward to collaboration on actual treatments. Similar considerations can be applied to the treatment of encaustic paintings and works that incorporate natural or microcrystalline waxes.

Thermally enhanced enzymatic cleaning

Enzymatic treatment methods offer significant advantages in terms of selectivity and nuanced action, which depend on the concentration of the enzyme, the pH of the medium, and temperature. However, this approach has not been exploited to date. According to Arrhenius' equation, the reaction rate doubles for every 10°C rise, so a temperature rise as low as 2°C within the bioactive temperature range may increase catalytic activity by 10–20%, and a 10°C rise by 50–100%, reducing the required enzyme concentration and exposure time while enhancing enzyme efficiency. AMH transfer could facilitate the enzymatic cleaning of mural paintings in situ, under conditions in which the enzymes are inactive due to the low ambient temperature. Since 2013, diverse AHM enzymatic treatments have been conducted on works on paper at the Lithuanian National Museum. At the Munch Museum in Oslo, several types of enzymes are being tested in conjunction with AMH transfer to remove the glue residues from water-soluble under-bound paints. Conservators have been seeking innovative cleaning methods in which enzymatic activity is controlled with AMH to compensate the reduced enzyme concentration, water content, and limited exposure time (Figure 8).

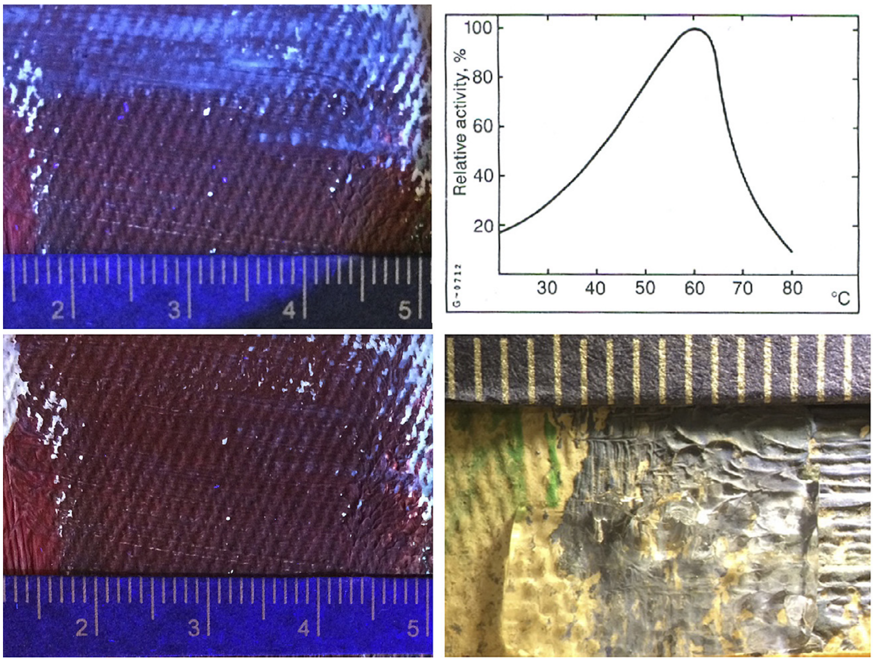


Figure 8. Test removal of glue residues with Gellan gel and Alcalase 2.4 L. Stereomicroscopy image: the glue residues emit pale bluish UV fluorescence (left). Graph showing increase of Alcalase relative activity with increasing temperature (top right). Gellan / Alcalase gel as seen under the microscope

CONCLUSION

The development of new, advanced materials and accurate sophisticated instrumentation is of fundamental importance to best practices. This paper provides examples of new approaches to heat transfer in the conservation of contemporary and modern art. The newly introduced technology meets the critical need for instrumentation able to deliver accurate mild warming and responds to the age-old problem in conservation of gaining control over heat transfer. Flexible AMH mats and IMAT, as developed and tested by the authors, are portable, sophisticated, and yet simple to use tools that meet the everyday needs of conservators. The associated treatment methodology will further evolve with the broader uptake of the new instrumentation, but the presented case studies illustrate the spectrum of new possibilities, with the full potential still to be discovered. Research on flexible AMH mats and IMAT emphasizes the fundamental importance of the integration of the new materials and nanomaterials into conservation. These efforts greatly contribute to the advancement of treatment capabilities within the margins of minimal intervention and risk, while achieving the maximum result.

NOTES

[1] The IMAT (Intelligent Mobile Accurate Thermo-Electrical mild heating device) project under the European Commission's 7th Framework Program (FP7) for research, coordinated by the University of Florence, created a series of flexible mats made with nanomaterials that are able to deliver heat at the specified level of control and in ways previously unattainable.

MATERIALS LIST

Alcalase 2.4 L proteinase from *Bacillus licheniformis*
Novozymes, www. novozymes.com

Dartek, 75 mil cast nylon film
Talas, NYC, USA

Dibond, 3 mm, Alucobond
Sun Supply Inc.
Portland OR, USA

Prototype mat
Instrumentors Supply, Inc.
Oregon City OR, USA

Reemay®, 2014 spunbonded polyester
TALAS
New York NY, USA

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