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The influence of the composition and additives of beeswax mixtures in historical ceroplastics on their long-term stability

Jan Krejčí, Martina Ohlídalová, Petra Korandová, Olga Trmalová, Romana Kirchnerová
National Museum, Václavské náměstí 68, 110 00 Praha 1 - Nové Město
E-mail: jan.krejci@nm.cz

The study examines the influence of the composition and additives in beeswax mixtures used in historical ceroplastics on their long-term stability. Based on analyses of historical recipes and research into collection items, experimental wax mixtures with various additives (lard, Venetian turpentine, dammar, paraffin, pigments) were prepared and subsequently subjected to workability tests, measurements of physical properties, and artificial aging. The results show that additives significantly affect not only the rheological properties of the mixtures, but also their chemical and thermal stability. While some additives contribute to increased stability, others (especially combinations of pigments with reactive components) can initiate degradation processes. The study provides new insights into historical technologies and provides a basis for the formulation of methodological recommendations in the field of preventive conservation and restoration of ceroplastic works.

INTRODUCTION

Ceroplastics, an artistic craft technique for producing artistic objects from wax, has been known since ancient times. It reached its peak in the 18th and 19th centuries, when free wax sculptures, genre relief scenes, and popular wax dolls dressed in clothes were created. Wax was also used in folk and monastic art, where wax reliefs were supplemented with wire mountings to form images of saints and reliquaries. It also proved to be a very suitable material for the production of anatomical models. In addition to imitations of plants and animals, models of entire human figures were created, which can still be found today in historical cabinets of curiosities or panopticons. The pinnacle of this artistic craft technique are portrait ceroplastics (so-called wax pousseé), which appeared at the turn of the 17th and 18th centuries in the bourgeois environment and subsequently became part of aristocratic culture [1-3].

From a technical point of view, ceroplastics are very diverse works which, despite being widely represented in museums and private collections, have always remained somewhat on the margins of professional research. Due to their diversity and high sensitivity to storage and display conditions, they present a wide range of problems today (Figs. 1-3). The most common is mechanical damage, where less solid and unprotected parts of the ceroplastics (e.g., limbs of figures, flowers, leaves, etc.) break or snap off [4]. It can be assumed that, as with sealing waxes, this mechanical damage is also directly related to the increase in hardness and brittleness of waxes, which waxes naturally undergo during aging [5]. However, in order to establish responsible preventive care for this type of object, we are also interested in how to prevent the fading of wax sculptures, the formation of efflorescence, and the possible spreading of reliefs recorded on historical wax sculptures across museum collections in the Czech Republic.

Depending on the nature of the intended work, various additives were added to beeswax in order to modify its physical and rheological properties and thus enable the production of ceroplastics. The exact recipes for wax mixtures were often kept secret by individual artists and workshops as trade secrets, and if they have been preserved in historical literature, they are usually incomplete, and the proportions of raw materials are only approximate. For example, Vasari states that wax was softened by adding lard, while turpentine increased its toughness, and black pitch affected the color and final consistency of the mixture. A more detailed recipe is known from the correspondence of British modeler John Flaxman, who recommends a combination of virgin wax, white wax, and Venetian turpentine, with the resulting

Fig. 1. Unknown woman, 1857, author unknown, bourgeois production (H2-158313) – detail of mechanically damaged facial area

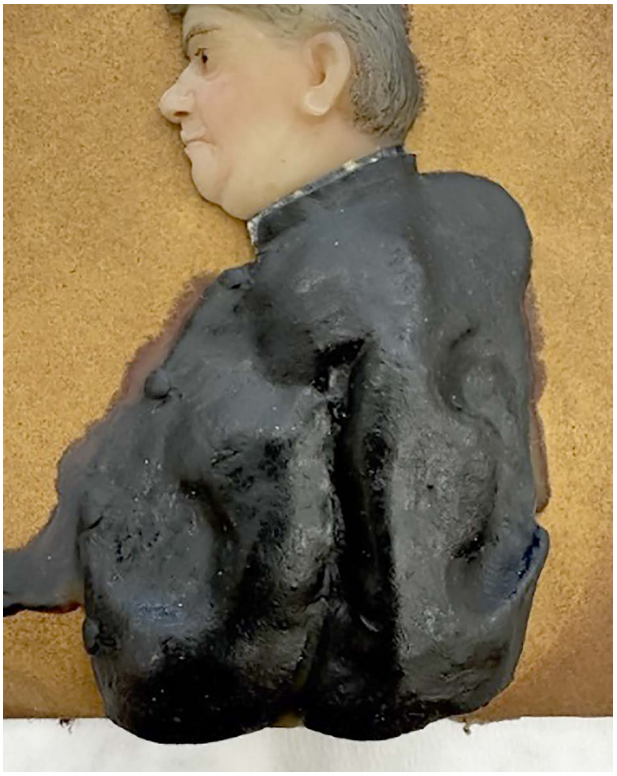

Fig. 2. Unknown priest, first half of the 19th century, author unknown (H2-15154) – detail of the body damaged by high temperatures

Fig. 3. Portrait doll of King Edward VII, 1892, probably by the Pierotti family (H2-182823) – detail of efflorescence

mixture intended for soft modeling. The use of virgin wax, produced by young bees, indicates an emphasis on the purity and lightness of the material. These historical recipes demonstrate that the selection and ratio of additives had a fundamental influence on the workability, mechanical properties, and aesthetic result of ceroplastic works [6-7].

However, the composition of the wax mixture varied significantly depending on the chosen processing technique. For hand-modeled sculptures, it was necessary to prepare a so-called soft mixture that could be easily worked at human hand temperature. In addition to Venetian turpentine, which was added almost universally, animal fats and oils were added to soften the mixture and increase its plasticity. In contrast, a so-called hard mixture, which exhibited higher strength after hardening, was suitable for casting into molds. To produce it, natural resins such as colophony, black pitch, or unpurified black pitch were added to beeswax, which was often used as a filler for the non-visible parts of castings [8].

The color of the mixture was determined primarily by the color of the wax used and the additives added, or the mixture was tinted by adding powdered pigments. Monochrome reliefs often imitated noble materials such as ivory, marble, or terracotta. Polychrome portrait reliefs used pigments such as lead white, vermilion, or minium to achieve a realistic skin tone. The final appearance of the sculpture could be complemented by "dressing" – covering selected parts with a colored wax shell – or coloring with oil paints [9].

The results of GC/MS analyses performed on selected historical wax portraits from the collections of the National Museum from the 18th and 19th centuries confirmed the presence of specific additives in historical wax mixtures, namely drying oil, Venetian turpentine, pine resin, animal fat, and vegetable gums. Raman spectroscopy identified the main pigments in the mixtures as vermilion, minium, a mixture of the two, lead white, and less frequently others.

Restoration of wax mixtures is a complex task, and in the case of ceroplastics, this complexity is further increased by the variability of wax compositions [9]. However, how the exact composition of these mixtures influences the long-term stability of ceroplastic works has not yet been systematically investigated. This gap in knowledge significantly limits the ability to predict material behavior and to design effective conservation strategies. The above findings provided a valuable basis for the design of experimental mixtures, the properties and stability of which are the subject of this study. Its main objective was to identify factors that negatively affect the long-term stability of the wax matrix of ceroplastic portraits. Two different aspects were considered in the evaluation. First, various additives (lard, resins, pigments, etc.) were examined as potential accelerators of the degradation of beeswax-based mixtures, which

had been proven to have been added to the mixture by the authors themselves in the past to achieve the desired properties of the material – softness, ductility, color, etc. Furthermore, various degradation influences acting in the environment were also examined to find conditions that accelerate the aging of wax mixtures and to trace similarities with the resulting state of the material in degraded historical ceroplastics. The study thus contributes not only to the knowledge of historical procedures, but also provides a basis for the formulation of methodological recommendations for current conservation practice in the principle of preventive care.

EXPERIMENTAL

Mixtures, model samples

Based on research into historical recipes and the results of field and conservation surveys, wax mixtures were prepared for both casting and direct modeling of ceroplastics [10-12]. Dammar (chosen as a general representative of natural resins), Venetian turpentine, pork lard and paraffin were chosen as modifiers of the rheological properties of natural beeswax. Vermilion and lead white pigments, as well as a combination of vermilion and minium, were used to color the wax mass. For comparison, samples of pure paraffin and a mixture of beeswax and paraffin in a 1:1 ratio were also prepared [12]. An overview of all prepared mixtures and their ratios is given in Table 1.

Tab. 1 Overview of the modeling mixtures studied and their designation; the letter indicates the type of component (beeswax, paraffin, dammar, venetian turpentine, lard, vermilion, minium, lead white), the following number then % by weight content of the composition

Mixture composition	Label of mixture
beeswax	B100
paraffin	P100
beeswax + dammar 5%	B95D05
beeswax + dammar 10%	B90D10
beeswax + dammar 20%	B80D20
beeswax + Venetian turpentine 1%	B99T01
beeswax + Venetian turpentine 5%	B95T05
beeswax + Venetian turpentine 10%	B90T10
beeswax + paraffin 50%	B50P50
beeswax + lard 1%	B99L01
beeswax + lard 5%	B95L05
beeswax + lard 10%	B90L10
beeswax + vermilion 1%	B99V01
beeswax + vermilion 5%	B95V05
beeswax + vermilion 10%	B90V10
beeswax + vermilion 20%	B80V20
beeswax + vermilion 5% + minium 5%	B90V05M05
beeswax + lead white 1%	B99W01
beeswax + lead white 5%	B95W05
beeswax + lead white 10%	B90W10
beeswax + lead white 20%	B80W20

The wax mixtures were melted and mixed in aluminum bowls and then poured directly into silicone molds. Beams measuring 10 × 10 × 100 mm were selected as the appropriate specimen shape. Smaller pieces were then taken from these for further testing and, where necessary, reshaped into other test specimens for colorimetry, modulus measurements, FTIR and DSC analysis.

No visual differences in solidification speed were observed between the individual mixtures. All samples – except for pure paraffin – showed volume shrinkage of between 1% and 5% after solidification. Paraffin showed almost no shrinkage.

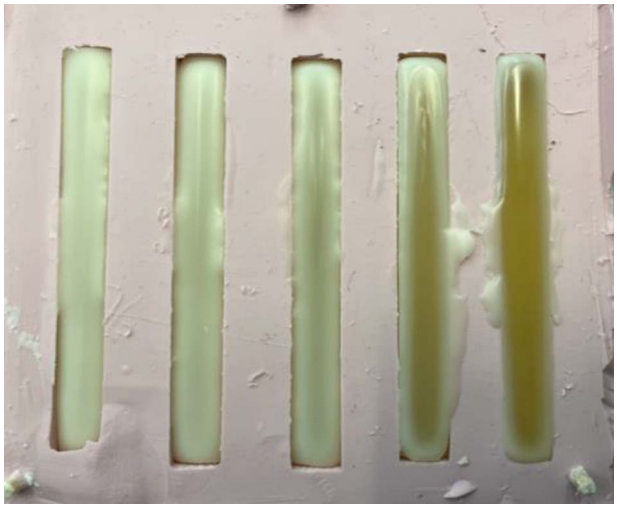

Fig. 4. Shot of casting wax samples

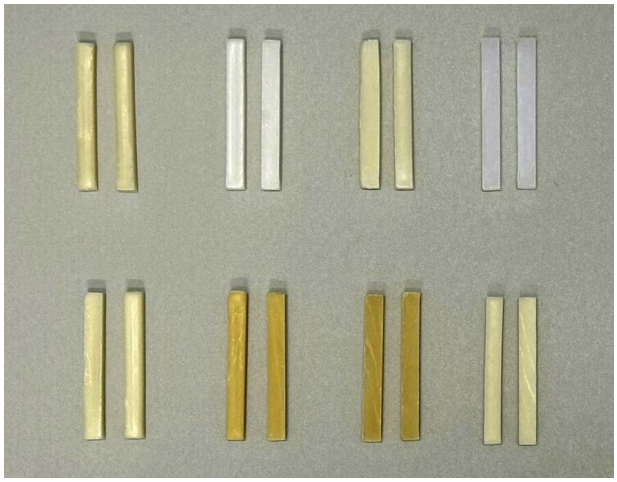

Fig. 5. Documentation of selected finished cast beams

Workability properties of mixtures, hardness and melting point

An experienced conservator evaluated the following properties: ease of working with tools, modelling properties (including softening in the hand and with temperature), smoothing, visual appearance of the work and the resulting relief, adhesion of accessories, crumbling, adhesion to impurities, and overall perceived hardness/softness. Subsequently, the additives of the individual components that are optimal for the given purpose were selected, e.g., for modeled relief or, conversely, for casting from a mold, etc.

For each wax mixture and standard, the melting point was determined on a Stuart MP-200d digital melting point apparatus and the hardness was determined using the Shore A method (HA).

Artificial aging and impact on long-term stability of mixtures

Prepared specimens of selected mixtures (B100, B95D05, B95T05, B50P50, B95L05, B95V05, B90V05M05, and B95W05) were exposed to three types of artificial aging conditions designed to simulate various external influences.

- **aging by heat:** 200 °C, 3 h; Memmert UFE 400 [13]
- **aging by light (Q-sun):** simulated by exposure to UV/VIS radiation at a temperature of 45 °C for 240 hours in a Q-Sun Xe-1 BC device. The radiation source was a xenon lamp with an irradiance of 0.45 $W.m^{-2}$ at a wavelength of 420 nm, which corresponds to the simulation of sunlight at midday in summer after passing through a glass window
- **aging by freezing**: –32 °C, 336 h; Liebherr GX 823 [14]

Selected samples after aging were subsequently subjected to colorimetry, modulus measurement, FTIR spectroscopy and DSC analysis.

Colorimetry

The effect of additives in the studied wax mixtures on their color under artificial aging conditions was evaluated using colorimetric measurements at five randomly selected points on each sample. The color was measured using a Konica Minolta CM-600d spectrometer in the CIELAB color space, D65, aperture 8 mm, specular component included. The measured data were processed in the SpectraMagic NX program. The total color difference resulting from artificial aging was calculated**,** measurement errors were processed based on Gauss's law of uncertainty distribution.

Modulus of elasticity in tension

The modulus was measured on test samples that had been subjected to artificial aging conditions (according to ISO-527, clamping length 20 mm, displacement speed 1 $mm.min^{-1}$, constant temperature 25 °C), which was performed at the Department of Chemical Technology of Monument Conservation, University of Chemistry and Technology, Prague, on a LabTest 5.030-2 universal testing machine. Each measured set contained 5 samples, with the result being their arithmetic mean.

Fourier-transform infrared spectroscopy (FTIR)

Each wax mixture studied before and after artificial aging of the samples was also studied using Fourier-transform infrared spectroscopy with the ATR technique. Analysis was performed by the FTIR spectrometer Nicolet iN10 in combination with the iZ10 module with ATR adapter (with a single reflection diamond crystal) and DTGS detector operating at room temperature. Measurement parameters: spectral range 4000-650 cm^{-1} resolution 4 cm^{-1} number of accumulated spectra 64, apodization N-B strong. All spectra were evaluated using the Omnic 32 software.

DSC analysis

For the calorimetric experiments, a DSC3+ instrument (Mettler Toledo) was used. Measurements were carried out under a nitrogen atmosphere at atmospheric pressure, using aluminum crucibles. The investigated temperature range was –10 to 165 °C, with heating and cooling rates of 1 $°C \cdot min^{-1}$.

Measurements were performed on mixture samples both before and after artificial aging, in the Thermal Analysis Laboratory of the Institute of Chemical Technology, Prague.

RESULTS AND DISCUSSION

Workability properties of mixtures, hardness and melting point

The experimentally obtained results of the studied wax mixtures are summarized in Figure 6. The melting point of beeswax mixtures with the additives to modify rheological properties changes slightly. For pure beeswax without additional additives, the value was determined to be 61 °C. The graph shows that the addition of paraffin, Venetian turpentine, or lard shifts the melting point of the mixtures to lower values. The lowest (apart from pure paraffin P100) is found in mixture B90L10. Conversely, the addition of pigments shifts it to higher values, with a slightly steeper increase indicated for additions of vermilion (up to 66 °C). The Shore A hardness values (25 °C) correspond relatively well with the measured melting point. Mixtures with added pigments exhibit higher hardness than the standard pure beeswax B100 (HA72). On the other hand, pure paraffin P100 (HA59) has the lowest hardness of those measured, but it has been shown that, given the ratio in the mixture, it softens less effectively than lard or Venetian turpentine.

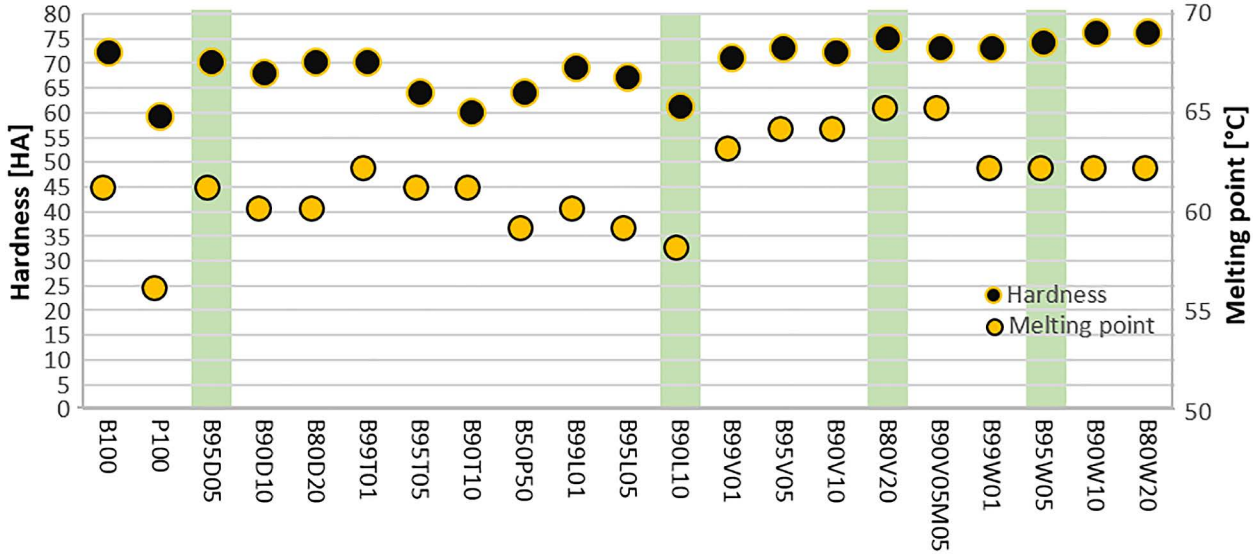

Fig. 6. Overview of the basic properties of the wax mixtures studied (Shore A hardness, melting point (°C); mixtures with interesting properties in terms of processing characteristics are marked in green (see below)

In terms of workability, lard proved to be a more effective softener for modeling mixtures, exhibiting excellent adhesion of additives to the wax surface when added in higher amounts (10%), better than mixtures with Venetian turpentine.

A general finding was that during manual modeling of beeswax and mixtures, dust impurities were trapped, leading to undesirable darkening of the material. This effect was partially eliminated only by the addition of lead white, with the optimum being mixture B95W05. However, practical tests showed that lead white is not suitable for modeling mixtures – its addition impairs the workability of the material and, at higher concentrations, causes the mixture to become brittle and even breakable. Nevertheless, the use of lead white seems very suitable for casting into molds.

With lead white and higher concentrations of vermilion, pigment sedimentation occurred at the bottom of the mold [15]. In the case of vermilion, however, the castings were generally more evenly colored. At pigment concentrations above 5% by weight, no significant differences in the color of the mixtures were observed.

In the case of casting mixtures, dammar resin in a quantity of 5% proved to be a suitable additive. In this ratio, the mixture exhibited sufficient hardness while remaining easy to work with – it was possible to cut, carve, smooth, and add to it without the need for further reinforcement. Although dammar is a relatively hard resin in itself, its addition to the wax mixture had a softening effect, which is consistent with the literature [15-16].

An interesting finding was the effect of adding vermilion on the workability of the relief. In mixtures without vermilion, but also with lower additions (1-15%) of vermilion, the surface of the wax turned white during machining, but in mixture B80V20, the surface remained uniformly colored even after processing, and the resulting impression was not disturbing in any way.

Artificial aging and impact on long-term stability of mixtures

Colorimetry in CIELAB color space

The results of color measurements (Fig 7) indicate a significant degrading effect of high temperatures on wax mixtures containing additions of Venetian turpentine, paraffin, lard, and especially lead pigments (minium, lead white). The color shift occurs mainly on the L^* (darkening) and b^* (yellowing) axes. In contrast, pure beeswax and mixtures with dammar admixtures or mixtures pigmented with vermilion resisted these conditions better, but even these achieved a total color difference value of 5 or more. Thus, degradation was also evident in these mixtures.

Exposure to light radiation (Q-sun) caused fading in the mixtures examined (including pure beeswax), with the change being comparable in all cases. Artificial aging by freezing (–32 °C, 336 h) did not actually lead to any color changes.

Modulus of elasticity in tension

Contrary to expectations that the measurement of tensile modulus would confirm the behavior of the mixtures indicated by the measurement of hardness and the evaluation of processing properties, the actual measured values of modulus did not show any of the expected trends. Thus, this measurement did not reveal any influence of the type of additive added to the wax

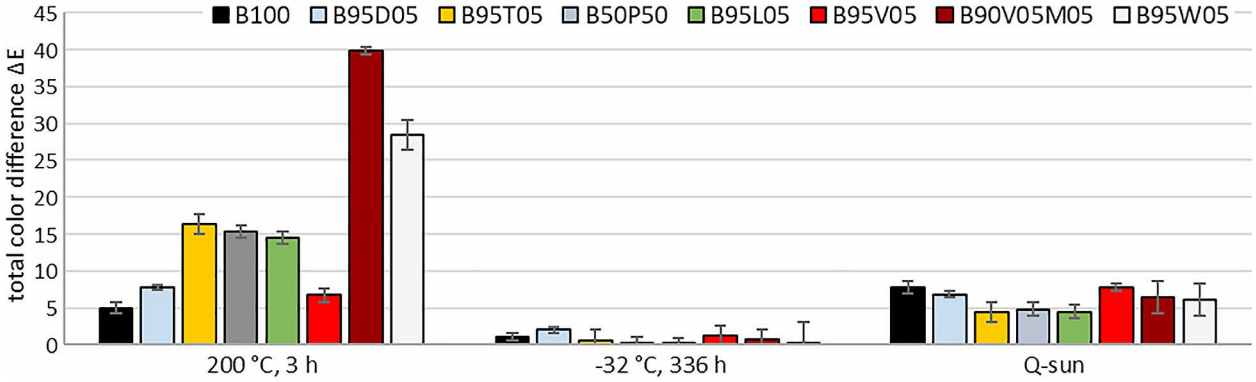

Fig. 7. Comparison of the total color differences of model mixtures as a result of artificial aging by heat (200 °C, 3 h), freeze (-32 °C, 336 h), and light (Q-sun)

mixture on the mechanical properties of the material. Similarly, the effect of artificial aging conditions was not apparent in any sample to such an extent that it could be interpreted in any way.

It can therefore only be stated that the modulus of elasticity values ranged from approximately 130 to 200 MPa, with no noticeable correlation to the composition of the mixture or the conditions to which it was exposed. Artificial aging did not result in any measurable changes in mechanical properties.

FTIR

Significant changes were observed in the infrared spectra of most mixtures of beeswax with additives exposed to heat aging conditions. Thermal degradation is reflected in the infrared spectrum of beeswax with additives by significant changes that indicate the breakdown of its chemical structure. Selected changes in the model mixtures are shown in the graphs in Figures 8-9. The loss of the absorption band in the 3320–3330 cm^{-1} range is a result of dehydration or decomposition of hydroxyl groups. The disappearance of absorption bands in the 1730–1710 cm^{-1} range indicates the decomposition of less stable carbonyl groups of esters with shorter linear chains. Meanwhile, band 1737 cm^{-1} corresponding to thermally more stable long chains [17], remains unchanged for all mixtures. The loss of the band at 1050 cm^{-1} indicates the disruption of C–O bonds typical of esters and alcohols. The loss of bands at 993 and 946 cm^{-1} indicates the disappearance of unsaturated hydrocarbon

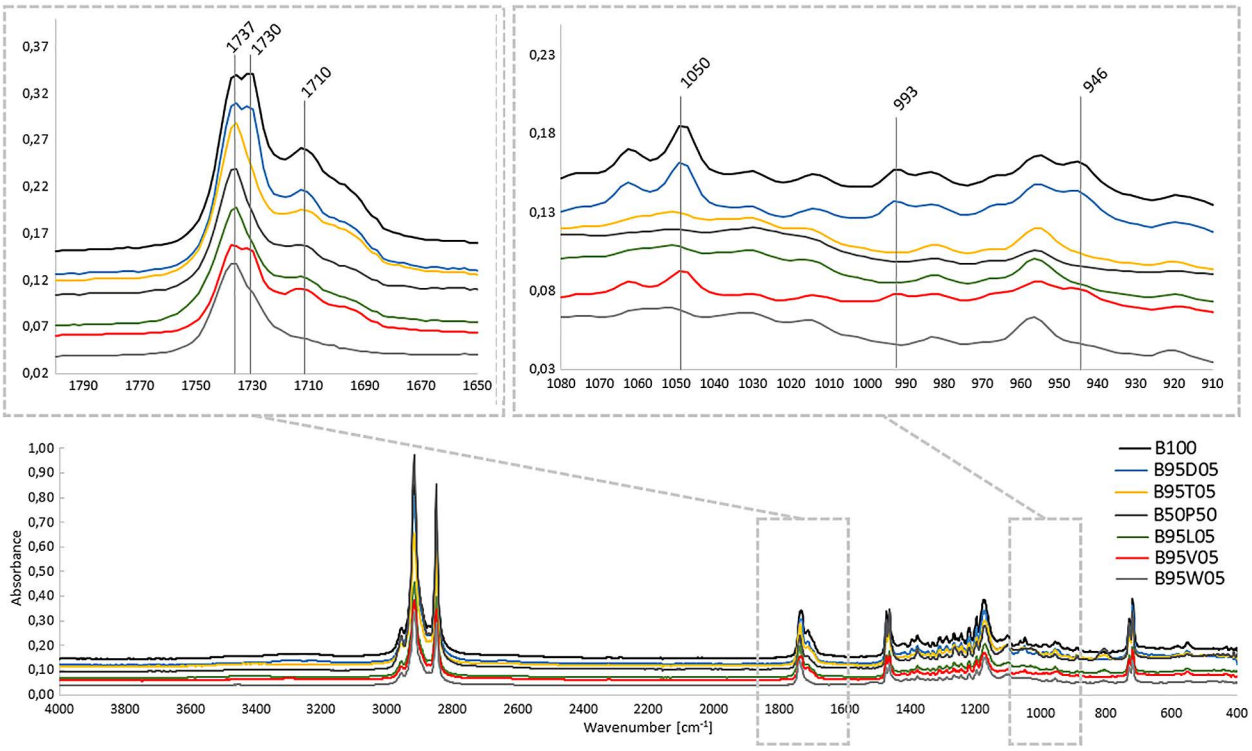

Fig. 8. FTIR spectroscopy of heat aged beeswax mixtures (200 °C, 3 h)

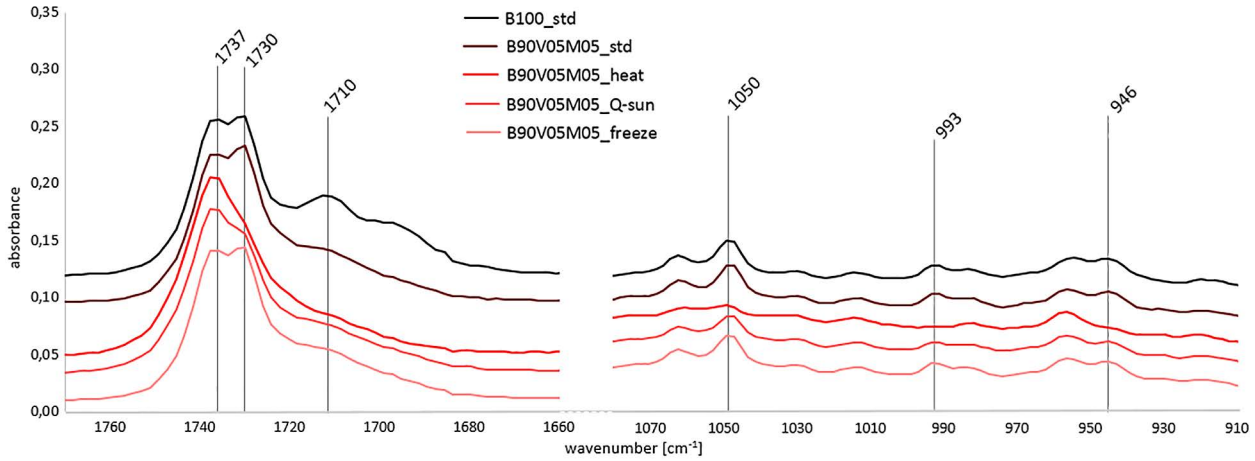

Fig. 9. FTIR spectroscopy of a mixture containing both vermilion and minium (B90V05M05) according to the method of artificial aging; comparison with unaged pure beeswax (B100)

structures; these changes are observed in all mixtures of beeswax with additives such as Venice turpentine, paraffin, lard, as well as lead white and mixtures with combination of vermilion and minium. They were not observed only in the standard beeswax and mixtures with dammar or with vermilion alone [18-19].

In addition to thermal damage of beeswax with selected additives, degradation changes were also observed in a mixture of beeswax with combination of vermilion and minium after exposure to light aging conditions (Q-Sun). Even after this, the decomposition of the carbonyl group of esters with shorter linear chains occurred in this mixture due to photooxidation, which resulted in a significant decrease in the 1730 cm^{-1} band while the carbonyls 1737 cm^{-1} of less reactive esters with longer chains remain again. Of all the mixtures tested, only this mixture (B90V05M05) showed degradation as a result of heating during preparation and casting, i.e., in an unaged sample. This was manifested by the disappearance of the 1710 cm^{-1} band, which remained present in all other unaged mixtures. The overall instability of this mixture corresponds to its significant color change due to the effect of increased temperature.

The results of FTIR spectroscopy clearly show that the stability of beeswax during heat and light aging is significantly affected by the presence of additives. While pure beeswax and its mixture with vermilion or dammar showed high resistance to degradation changes, mixtures containing reactive components such as Venice turpentine, lard, lead white, or a combination of vermilion and minium showed significant changes in the area of carbonyl, aliphatic, and hydroxyl vibrations. These changes indicate the decomposition of ester bonds, oxidation of unsaturated structures, and dehydration, suggesting a disruption of the chemical integrity of the wax matrix.

Special attention should be paid to the mixture of beeswax with combination of vermilion and minium, which proved to be the most reactive. While vermilion alone showed no degradative effect, its combination with minium led to a significant decrease in the carbonyl group band during light aging, which can be attributed to photooxidative processes initiated by the presence of minium. This pigment, containing lead oxides, can act as a photocatalyst that accelerates the decomposition of the ester structures of beeswax.

DSC analysis

The endothermic peaks in the DSC heating curve of the studied beeswax (Fig. 10) at 43 °C, 51 °C, 54 °C and 59 °C correspond to the polymorphic transitions of the orthorhombic phase of wax. The transition at the highest temperature corresponds to the melting point of beeswax, while lower temperatures are then explained either as transitions in the solid phase from low-temperature rhombic to less ordered rotational phases, or as a gradual increase in the liquid phase content. Transitions to rotational phases are associated with softening of the material [20].

The temperature transitions observed in the DSC curve of beeswax remain consistent even after the addition of Venetian turpentine, lard, or dammar resin at a concentration of 5% by weight, which indicates that the original crystalline structure of the wax is preserved. Even the pigment vermilion did not interact with the wax at a level that would affect its thermal behavior in the concentration range studied. A slight change was only observed in the mixture with lead white, where a new, broad endothermic band begins to appear at 85 °C at concentrations above 5% (Fig. 10). This band becomes more pronounced with increasing pigment concentration, which probably indicates the formation of a new phase or the interaction of the pigment with the wax at higher temperatures. The same band was also detected in a mixture containing 5% of vermilion and 5% of minium, where a synergy between the pigments can be considered.

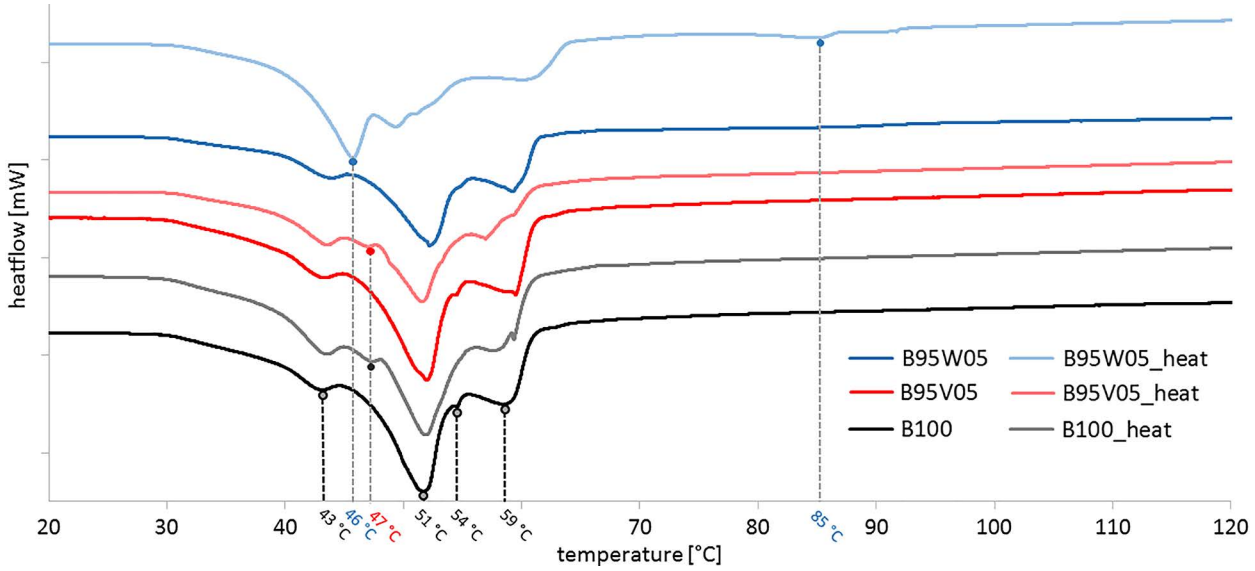

Fig. 10. DSC curves of pure beeswax (B100) and mixtures of beeswax with 5% vermilion (B95V05) and 5% lead white (B95W05) before and after artificial heat aging (200 °C, 3h), with marked positions of polymorphic transition bands of beeswax and areas of change in aged mixtures

The DSC curves change significantly following artificial heat aging, which indicates the relative stability of wax mixtures under normal conditions, but also their sensitivity to thermal stress. After artificial aging, a new small endothermic band appears at 47 °C in the DSC curve of pure wax and the mixture with 5% of vermilion, which may indicate phase reorganization or interaction of the pigment with wax degradation products. The most significant change was observed in the mixture with 5% lead white, where the main endothermic band shifted to 46 °C, indicating a disruption of the original crystalline structure of the wax (Fig. 10).

Under all tested conditions, dammar additive appears to be compatible with wax, without significant interaction at the crystallinity level. Mixtures of wax with Venice turpentine and lard, after exposure to thermal aging, show a shift of the main endothermic band to 44 °C in DSC curves. These additives act as plasticizers, lowering the melting point of the wax and increasing the amorphousness of the mixture.

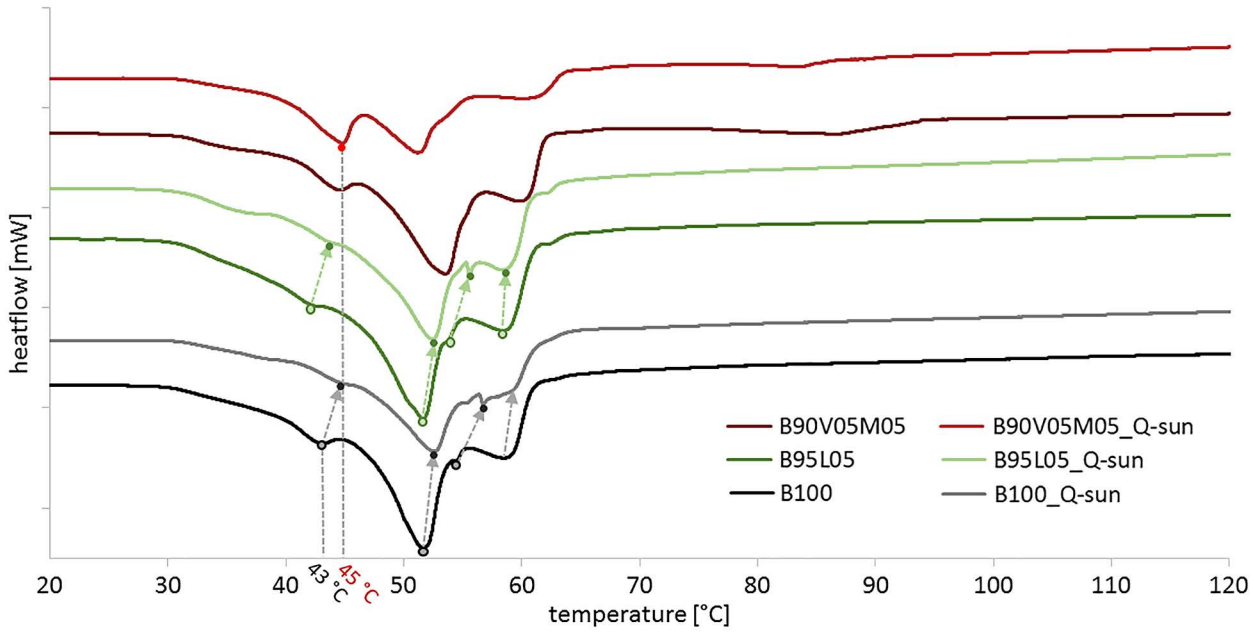

Fig. 11. Comparison of DSC curves of beeswax (B100), a mixture of beeswax with 5% lard (B95L05), and beeswax pigmented with a combination of 5% vermilion and 5% minium (B90V05M05), before and after artificial aging with light (Q-Sun); changes indicated by DSC curves and shifts in certain areas

After exposing mixtures of beeswax to artificial aging by light, minor changes were observed in the DSC curves. In beeswax alone and in almost all mixtures, the front part of the heating curve was smoothed out, specifically the endothermic band around 43 °C shifted and almost disappeared (Fig. 11). This indicates the degradation of components responsible for low-temperature polymorphic transitions. Overall, exposure to light causes some mixtures (e.g. B100, B95L05) to undergo a transformation of components with lower melting points or changes in the crystalline phase. This leads to a shift in the characteristic wax bands towards higher temperatures in the DSC curves. The literature even states that the degradation of wax mixtures can lead to a measurable increase in melting temperature if the changes in composition occur [21]. Only the DSC curve of the mixture of wax with the addition of 5% vermilion and 5% minium showed a completely different course; in addition, the identified transitions are shifted overall to higher temperatures already happened in the case of the non-aged sample (degradation of the wax mixture because of melting during casting). This fact correlates well with the results of FTIR spectroscopy (see Fig. 9). After artificial aging by light, there was a significant relative increase in the intensity of the band around 45 °C, indicating enhanced interaction of the pigments with the wax or the formation of a new crystalline domain. This synergistic effect of the pigments may have a significant impact on the stability.

After artificial aging by freezing, no significant changes in the DSC curves were observed in most samples. The exception was a mixture of wax with 5% vermilion, where there was a slight thickening and sharpening of the band at 60 °C. This change may be related to the reorganization of the crystalline phase of wax induced by low temperature, but without significant disruption of the structure.

CONCLUSIONS

The results of thermal analysis and infrared spectroscopy clearly show that the stability of wax mixtures used for the production of ceroplastics is significantly influenced by the type of additive used. Softeners such as lard and Venetian turpentine improve the modelling properties of the mixture, but at the same time reduce its thermal stability and increase its sensitivity to degradation during thermal and light aging. Additives such as dammar contribute to the preservation of the crystalline structure and exhibit high resistance to aging, which is confirmed by both stable DSC curves and minimal changes in infrared spectra. Paraffin as an additive significantly modifies the properties of the mixture, which then becomes sensitive to thermal and light aging, which can be risky in terms of the long-term stability of the ceroplastics.

Pigments generally do not affect the thermal behavior of mixtures at low concentrations, but at higher concentrations or in combination with reactive components, they can initiate degradation processes. Lead white has a particularly significant effect, showing signs of chemical interaction with wax. The combination of vermilion and minium proved to be critical, where photo-oxidative decomposition of ester structures initiated by the presence of lead oxides occurred during light aging. The mixture with vermilion alone shows high resistance to degradation changes, both in terms of thermal behavior and chemical integrity.

Overall, the results of this study suggest that historical wax mixtures used in the production of ceroplastics show considerable variability in their long-term stability, which is closely related to the type and amount of additives added. Special attention should be paid to red-toned mixtures, in which the presence of a combination of vermilion and minium cannot be ruled

Tab. 2 Summary – additives to wax mixtures, their effect on properties and long-term stability

Type of additive	**Effect of addition**	**Long-term stability of the mixture**
dammar	increased hardness, good for cutting and carving	sufficient long term-stability
Venetian turpentine	softening for modelling, improved workability	sensitive to heat
paraffin	change of plasticity, reduced stickiness	sensitive to heat and light exposure
pork lard	softening for modelling, increased adhesion of addition	sensitive to heat and light exposure
vermilion	pigmentation	sufficient long-term stability
vermilion + minium	pigmentation	extremely sensitive to heat, sensitive to light
lead white	pigmentation, thickening , increased hardness goo for molding	sensitive to heat

out without detailed analysis. This combination proved to be highly susceptible to photo-oxidative degradation in the experiment, which has direct implications for the setting of storage conditions.

The following table summarizes the findings of this study in terms of the purpose of additives and the suitability of modifying the properties of wax mixtures used in the production of historical ceroplastics, and highlights problematic issues in terms of their long-term stability.

Based on this knowledge, it is possible to set parameters for the preventive conservation of ceroplastics. It is necessary to minimize exposure to light, not only UV but also visible radiation, which can initiate degradation processes, especially in pigmented mixtures. Ensure a stable temperature regime, with an emphasis on preventing overheating, especially in the summer months or when illuminated by warm light sources. Take into account the potential presence of reactive pigments (e.g., minium) even where their occurrence has not been analytically confirmed and handle these objects with extreme care.

This study contributes to a deeper understanding of the degradation mechanisms of historical wax mixtures and provides important background information for formulating principles for the preventive care of ceroplastics in museum collections.

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