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Artuklu Humanities

Yağlı Boya Tabloların Konservasyon-Restorasyonunda Vernik Uygulaması: Regalrez 1094, Keton (MS2A) ve Dammar Reçine Verniğinin Karşılaştırılması

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Atf: Dallık, M. K. ve Emre, G. (2025). “Yağlı Boya Tabloların Konservasyon-Restorasyonunda Vernik Uygulaması: Regalrez 1094, Keton (MS2A) ve Dammar Reçine Verniğinin Karşılaştırılması”. *Artuklu Humanities*, 19, 1-28. <https://doi.org/10.46628/ahu.1645201>

Öz

Sanatçılar, geçmişten günümüze, resim üretiminde çoğunlukla ulaşabildikleri malzemeleri kullanmış; zamanla farklı estetik ve teknik amaçlarla yeni malzemeler de resim sanatına dâhil edilmiştir. Bu çeşitlilik, yağlı boya tabloların üretiminde kullanılan malzemelerin ve tekniklerin sayısını artırıp konservasyon ve restorasyon süreçlerinin de kullanılan malzemelere göre farklılaşmasına neden olmuştur. Özellikle verniğin eserle uyumu, çalışma prensibi ve geri döndürülebilirliği, konservasyon açısından kritik öneme sahiptir. Bu bağlamda, verniklerin yaşlanma sonrası fiziksel ve kimyasal özelliklerinin doğru biçimde saptanması hem eserin korunması hem de restorasyon uygulamalarının öngörülebilirliği açısından gereklidir. Bu çalışmada, konservasyon ve restorasyonda yaygın olarak kullanılan üç farklı reçine vernik türü; Regalrez 1094, keton reçinesi (MS2A) ve dammar reçinesi yapay yaşlandırma sürecine tabi tutularak incelenmiştir. Vernikler, en sık kullanılan uygulama kombinasyonları ile cam lamlar üzerine tatbik edilmiş ve kademeli UV yaşlandırma işlemine maruz bırakılmışlardır. Yaşlandırma öncesi ve sonrası numuneler, görünür ışık (VIS) görüntüleme, ultraviyole (UV) görüntüleme, ışık mikroskobu, taramalı elektron mikroskobu (SEM) ve nükleer manyetik rezonans spektroskopisi (NMR) yöntemleriyle analiz edilmiştir. Bulgular, yaşlandırmaya maruz bırakılmamış referans örneklerle karşılaştırılarak değerlendirilip konservatörlere malzemelerin uzun vadeli davranışları hakkında bilgi sağlanması amaçlanmıştır.

Anahtar Kelimeler: Dammar reçine, keton reçine verniği, regalrez 1094 verniği, vernik bozulması, restorasyon.

Makale Bilgileri											
Etik Beyan	Çalışmanın hazırlanma sürecinde bilimsel ve etik ilkelere uyulduğu ve yararlanılan tüm çalışmaların kaynakçada belirtildiği beyan olunur. Bu çalışma birinci yazarın, ikinci yazar danışmanlığında hazırladığı yüksek lisans tezinden üretilmiştir.										
Değerlendirme	İki Dış Hakem / Çift Taraflı Körleme										
Geliş Tarihi	27.02.2025										
Kabul Tarihi	14.08.2025										
Yayın Tarihi	30.12.2025										
Benzerlik Taraması	Yapıldı-ithenticate.com										
Yapay Zekâ Beyanı	Bu çalışmanın hazırlanma sürecinde yapay zekâ tabanlı herhangi bir araç veya uygulama kullanılmamıştır. Çalışmanın tüm içeriği, yazar tarafından bilimsel araştırma yöntemleri ve akademik etik ilkelere uygun şekilde üretilmiştir.										
Etik Kurul İzni	Bu çalışma İstanbul Üniversitesi Bilimsel Araştırma Projeleri Koordinasyon Birimi tarafından BAP-37602 proje numarası ile finanse edilmiştir. Yazarlar İstanbul Üniversitesi Bilimsel Araştırma Projeleri Koordinasyon Birimine şükran borçludur. Ayrıca Sezen Dallık ve Suna Dallık Öztürk'e teşekkür etmek isteriz.										
Etik Bildirim	artukluhumanities@artuklu.edu.tr										
Yazar Katkıları	<table border="1"> <tbody> <tr> <td>Araştırmanın Tasarımı</td> <td>Yazar -1 (% 50) - Yazar -2 (% 50)</td> </tr> <tr> <td>Veri Toplanması</td> <td>Yazar -1 (% 50) - Yazar -2 (% 50)</td> </tr> <tr> <td>Araştırma - Veri Analizi - Doğrulama</td> <td>Yazar -1 (% 50) - Yazar -2 (% 50)</td> </tr> <tr> <td>Makalenin Yazımı</td> <td>Yazar -1 (% 50) - Yazar -2 (% 50)</td> </tr> <tr> <td>Metnin Geliştirilmesi ve Tashihi</td> <td>Yazar -1 (% 50) - Yazar -2 (% 50)</td> </tr> </tbody> </table>	Araştırmanın Tasarımı	Yazar -1 (% 50) - Yazar -2 (% 50)	Veri Toplanması	Yazar -1 (% 50) - Yazar -2 (% 50)	Araştırma - Veri Analizi - Doğrulama	Yazar -1 (% 50) - Yazar -2 (% 50)	Makalenin Yazımı	Yazar -1 (% 50) - Yazar -2 (% 50)	Metnin Geliştirilmesi ve Tashihi	Yazar -1 (% 50) - Yazar -2 (% 50)
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Metnin Geliştirilmesi ve Tashihi	Yazar -1 (% 50) - Yazar -2 (% 50)										
Çıkar Çatışması	Çıkar çatışması beyan edilmemiştir.										
Lisans	Yazarlar dergide yayınlanan çalışmalarının telif hakkına sahiptirler ve çalışmalarını CC BY-NC 4.0 lisansı altında yayımlanmaktadır										
Dizinleme Bilgileri	Dergi; ERIH PLUS, DOAJ, EBSCO/(CEEAS), MLA, ProQuest Ulrich's Periodicals Directory, Linguistic Bibliography'de taranmaktadır.										

Varnish Application in Conservation-Restoration of Oil Paintings: Comparison of Regalrez 1094, Ketone (MS2A) and Dammar Resin Varnish

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Cite: Dallık, M. K. ve Emre, G. (2025). “Varnish Application in Conservation-Restoration of Oil Paintings: Comparison of Regalrez 1094, Ketone (MS2A) and Dammar Resin Varnish”. *Artuklu Humanities*, 19, 1-28. <https://doi.org/10.46628/ahu.1645201>

Abstract

Throughout history, artists have predominantly utilized materials that were readily accessible to them. Over time, driven by evolving aesthetic preferences and technical objectives, they began incorporating a wider variety of materials into their artistic practice. This diversification has significantly expanded the range of materials and techniques employed in oil painting, consequently requiring conservation and restoration approaches tailored to the specific properties of each material. Within this context, the compatibility of varnish with the artwork, its functional performance, and its reversibility are of critical importance. Accurate assessment of a varnish’s physical and chemical characteristics after aging is therefore essential for ensuring both the preservation of the artwork and the reliability of restoration interventions. This study investigates three resin varnishes that are widely used in conservation and restoration—Regalrez 1094, ketone resin (MS2A), and dammar resin—by subjecting them to artificial aging. The varnishes were applied to glass slides using the most employed application combinations and subsequently exposed to controlled ultraviolet (UV) aging cycles. Pre- and post-aging samples were analyzed through visible light (VIS) imaging, ultraviolet fluorescence (UVF) imaging, light microscopy, scanning electron microscopy (SEM), and nuclear magnetic resonance (NMR) spectroscopy. The results were compared with unaged reference samples to assess degradation patterns and long-term performance. The findings aim to provide conservators with a deeper understanding of the materials’ behavior over time, thereby informing more effective decision-making in conservation practice.

Keywords: Dammar resin, ketone resin varnish, regalrez 1094 varnish, varnish degradation, restoration.

Article Information											
<i>Ethical Statement</i>	It is hereby declared that all scientific and ethical principles were observed during the preparation of the study, and that all referenced works have been properly cited in the bibliography. This study is derived from the master's thesis prepared by the first author under the supervision of the second author.										
<i>Reviewers</i>	Two external reviewers / Double-blind										
<i>Date of Submission</i>	27.02.2025										
<i>Date of Acceptance</i>	14.08.2025										
<i>Date of Publication</i>	30.12.2025										
<i>Plagiarism Checks</i>	Done-ithenticate.com										
<i>AI Disclosure</i>	No artificial intelligence-based tools or applications were used in the preparation of this study. All content of the study was produced by the authors in accordance with scientific research methods and academic ethical principles.										
<i>Ethics Committee Approval</i>	This study was funded by the Scientific Research Projects Coordination Unit of Istanbul University under project number BAP-37602. The authors are grateful to the Scientific Research Projects Coordination Unit of Istanbul University. We would also like to thank Sezen Dallık and Suna Dallık Öztürk.										
<i>Complaints</i>	artukluhumanities@artuklu.edu.tr										
<i>Author Contributions</i>	<table border="1"> <tbody> <tr> <td>Conceptualization</td> <td>Author-1 (%50) - Author-2 (%50)</td> </tr> <tr> <td>Data Curation</td> <td>Author-1 (%50) - Author-2 (%50)</td> </tr> <tr> <td>Investigation - Analysis - Validation</td> <td>Author-1 (%50) - Author-2 (%50)</td> </tr> <tr> <td>Writing</td> <td>Author-1 (%50) - Author-2 (%50)</td> </tr> <tr> <td>Writing - Review & Editing</td> <td>Author-1 (%50) - Author-2 (%50)</td> </tr> </tbody> </table>	Conceptualization	Author-1 (%50) - Author-2 (%50)	Data Curation	Author-1 (%50) - Author-2 (%50)	Investigation - Analysis - Validation	Author-1 (%50) - Author-2 (%50)	Writing	Author-1 (%50) - Author-2 (%50)	Writing - Review & Editing	Author-1 (%50) - Author-2 (%50)
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<i>Conflict of Interest</i>	No conflict of interest declared.										
<i>License</i>	The authors own the copyright of their work published in the journal and their work is published under the CC BY-NC 4.0 license.										
<i>Indexing Information</i>	The journal is indexed in: ERIH PLUS, DOAJ, EBSCO/(CEEAS), MLA, ProQuest Ulrich’s Periodicals Directory and Linguistic Bibliography										

Introduction

Art production, from antiquity to the present day, has undergone continuous transformation in terms of both materials and techniques. Oil paintings, in particular, are complex, multilayered structures composed of diverse organic and inorganic components. Their deterioration is influenced by multiple factors, including environmental conditions, previous restoration interventions, the artist's painting techniques, and the specific materials employed (Casadio & Giangualano, 2004, p. 63–80).

The removal of deteriorated, non-functional surface materials and the application of a suitable replacement is both a necessity and a preventive measure against further damage. When a varnish layer has reached the end of its functional life, selecting the appropriate replacement material and application method becomes critical for the long-term preservation of the work. In this regard, conservators must possess a comprehensive understanding of the varnish's physical and chemical characteristics, application techniques, and anticipated aging behavior.

In the present study, two accelerated artificial aging periods-representing approximately 10 and 20 years of natural aging-were applied, alongside an unaged reference group. This approach enabled a comparative analysis of the differences between aged and unaged samples, thereby revealing each varnish type's long-term behavior. The three selected varnishes-dammar resin, Regalrez 1094, and MS2A ketone resin-were subjected to controlled UV aging. Changes in their chemical and physical properties were documented using ultraviolet fluorescence (UVF) imaging, light microscopy, scanning electron microscopy (SEM), and nuclear magnetic resonance (NMR) spectroscopy. The results provide insight into how material selection and application methods influence conservation outcomes, contributing to best-practice recommendations for varnish use in oil painting restoration.

Dammar, MS2A and Regalrez 1094 Resin Varnishes

Dammar, ketone and regalrez 1094 resin varnishes with low molecular weight contain differences according to their usage areas. The reasons for their preference have changed periodically. In terms of conservation, strength, stability and longevity are the main reasons for preference.

Dammar Resin Varnish (Maimeri Spray Dammar Varnish)

Dammar is usually de-waxed by adding alcohol, then shaken and the waxy precipitate allowed to take shape before being removed from the container (Painting Conservation Catalog Volume 1: Varnishes and Surface Coatings, p. 64). Unlike mastic, which has been used in Europe since ancient times, dammar was not introduced to Europe until the 19th century. Therefore, mastic was widely used in Europe until the 19th century (Mayer, 2002, p. 134). It has been used as varnish for oil paintings since the first quarter of the 19th century (Painting Conservation Catalog Volume 1: Varnishes and Surface Coatings, p. 63). Over the years it has been used by conservators as a consolidant, binder and for varnishing. Due to its long history of use, the properties of dammar are well known, which makes its application easier for conservators (Duijn, 2016, p. 128). It is a resin that is chemically classified as "triterpenoid". In terms of molecular weight; the average molecular weight is between 424-506. When examined physically, dammar resin is considered to be quite brittle when completely dry (Painting Conservation Catalog Volume 1: Varnishes and Surface Coatings, p. 64).

Since the recipes for dammar varnish are relatively simple/easy, small quantities can be prepared and used in a short time. Dammar in crystalline form can be stored indefinitely in an airtight container, tightly closed, in a dark and dry place. If the dammar is very old, solvents with higher aromatic content may be required to dissolve it (Painting Conservation Catalog Volume 1: Varnishes and Surface Coatings, p. 67). The primary stage of dammar degradation is auto-oxidation (self-oxidation). The primary initiators for auto-oxidation are photochemical (especially in areas near ultraviolet) and thermal energies. Auto-oxidation can be accelerated by the presence of ozone, hydrogen peroxide, chlorine, sulfur dioxide and

other gases in the environment. Among the products of auto-oxidation, yellowing caused by secondary reactions is a non-oxidative thermal process (Feller, 1985, p. 155).

Dammar degradation causes severe discoloration and changes in mechanical properties. The yellowing and browning of Dammar films is accompanied by the formation of cracks and changes in surface properties. In general, the degradation products appear to be more polar and less elastic than the original material (Buder, 2008, p. 913). The drying layer of Dammar varnish, due to its high molecular weight and aging, attracts dirt and dust from the environment and retains them on the surface. Due to its slow drying characteristic, the newly applied varnish must have been applied in a dirt-free environment (Painting Conservation Catalog Volume 1: Varnishes and Surface Coatings, p. 69).

MS2A Resin Varnish/Retouching Varnish (Kremer Hydroxylamine Hydrochloride Resin)

Ketone Resins based on condensation reactions involving methylcyclohexanone and/or cyclohexanone have a high refractive index and high solubility in low polarity solvents. Although the fast drying rate is an advantage in many cases, varnish films have been found to deteriorate even under museum conditions. A major problem with these resins is that the ketone groups and double bonds tend to degrade in light, leading to yellowing and loss of solubility over time (Routledge, 2000).

If MS2A resin varnish is applied properly, good results can be obtained. However, cleaning should be done with materials where the varnish layer is fragile, sensitive to scratches and abrasion, and care should be taken not to leave any traces (Painting Conservation Catalog Volume 1: Varnishes and Surface Coatings, p. 88). MS2A resin is a light-yellow resin produced in small particle structure. The optical appearance of MS2A resin varnish is considered one of its biggest advantages: it has a silky sheen (Carlyle, 1994, p. 53).

The saturation of MS2A resin varnish is not as good as dammar or the new low molecular weight synthetic resin varnishes, but much better than that of long chain polymers. It conforms well to the paint surface and, when properly applied, gives the paint surface a very vivid appearance. It is also much less yellowing than natural resins and can be easily preferred for use in high ultraviolet light conditions. MS2A resin has traditionally been found to be significantly more stable than the main ketone resins because it is more resistant to oxidation and has no serious problems with crosslinking. As a result of oxidation, solubility in apolar solvents decreases rapidly and other defects such as microscopic wrinkling can occur. These oxidized ketone varnishes are water sensitive and can condense and be damaged by fluctuations in temperature or relative humidity (de la Rie, 1993, p. 568).

Regalrez 1094 Resin Varnish (Kremer Non-Polar Hydrocarbon Resin)

Regalrez 1094 is a hydrocarbon, low-molecular resin soluble in aliphatic and aromatic solvents. Regalrez 1094 is used to saturate slightly opaque areas in paintings and as a varnish (Piena, 2001, p. 40). In some cases where the varnishes used on paintings are not suitable for conservation-repair for various reasons, this varnish type can be used instead of the existing varnish (Painting Conservation Catalog Volume 1: Varnishes and Surface Coatings, p. 109). To mention the physical properties of Regalrez 1094 resin varnish; it is solid, colorless, mixed with translucent particles and white in color. Considering its chemical structure; it is classified as 100% hydrogenated, low molecular weight, hydro carbon resin. Based on its appearance on the painting; saturation and display gloss are similar to ketone or natural resins (Painting Conservation Catalog Volume 1: Varnishes and Surface Coatings, p. 110). When the chemical degradation process of Regalrez 1094 resin varnish is examined, it shows aging characteristics by showing autooxidation primarily photochemically. In terms of dirt and dust retention with the effect of aging, the tests showed that the possibility of attracting dirt was low due to the high glass transition temperature. In terms of theoretical lifetime, the solubility and carbonyl values shown by infrared spectroscopy all remained stable after more than 2,000 hours of aging tests (de la Rie, 1993, p. 568).

In the light of all these tests and analyses, it is estimated that the stabilized Regalrez 1094 resin varnish is one of the most stable products used in restoration and conservation today (Painting Conservation Catalog Volume 1: Varnishes and Surface Coatings, p. 114). The positive aspect of the varnish is that it is

soluble in aliphatic (related to oil or suet) hydro-carbon solvents (with non-aromatic content). Another feature of Regalrez 1094 resin varnish is that it is insoluble in polar solvents such as acetone, ethanol-spirits or isopropyl alcohol. Regalrez 1094 may not be the best resin to use as a starting point for a matt varnish due to its natural gloss (Painting Conservation Catalog Volume 1: Varnishes and Surface Coatings, p. 111-112).

Methods

This study employed a comparative experimental design to evaluate the aging behavior of three widely used varnish types in oil painting conservation: dammar resin, MS2A ketone resin, and Regalrez 1094 hydrocarbon resin. The research process consisted of three main stages: preparation of varnish samples, accelerated artificial aging, and analytical characterization.

Sample Preparation

Each varnish type was applied to glass microscope slides using the most common application methods identified through an extensive literature review and current conservation practices. Application techniques included brush application, spray application, and airbrush application, either individually or in layered combinations. For each resin group, the combinations were selected to represent realistic conservation scenarios, while impractical or non-standard techniques were excluded.

The dammar resin solution was prepared at a concentration of 20% dammar to turpentine, stirred regularly to ensure homogeneity. Regalrez 1094 and MS2A resins were used in their standard conservation-grade formulations. All brushes used were 1 cm in width and dedicated to a single varnish type to prevent cross-contamination. Airbrush applications were performed with an MGF Compressors CS 30/155 model (2014) unit, using oil-free, filtered air. Application parameters included an air pressure of 10–15 psi (0.7–1 bar), a nozzle distance of 5–10 cm, and a nozzle diameter of 0.2–0.3 mm.

Artificial Aging Protocol

Accelerated UV aging was carried out in a custom-built, light- and air-impermeable chamber equipped with four SYLVANIA Blacklight-Blue F36W/BLB-T8 fluorescent lamps. The UV exposure periods were calibrated to simulate approximately 10 years (28 hours) and 20 years (56 hours) of natural aging, based on established correlations in the literature (Whitmore & Colaluca, 1995). A set of unaged reference samples for each varnish type was retained under stable laboratory conditions to enable comparative analysis. The chamber temperature was maintained at a consistent average throughout the exposure period.

Analytical Methods

The samples were examined before and after artificial aging using the following techniques:

- **Visible Light Imaging (VIS)** with a Canon EOS 600D digital camera (18 MP APS-C CMOS sensor), maintaining a distance of 20–25 cm between lens and sample, with manual ISO adjustments.
- **Ultraviolet Fluorescence Imaging (UVF)** in a darkened environment using UV-specific camera filters.
- **Light Microscopy** at $\times 2.0$ magnification for detailed surface inspection.
- **Scanning Electron Microscopy (SEM)** with a Jeol NeoScope JCM-5000 for microstructural analysis.
- **Nuclear Magnetic Resonance (NMR) Spectroscopy** with a Bruker Avance III HD 400 MHz to assess molecular-level degradation processes such as oxidation, depolymerization, and polarity shifts

Natural and synthetic varnishes remain soluble in mild solvents after 15 years. Hydrocarbon-based varnishes like Regalrez 1094 and Arkon P-90 were especially easy to dissolve, even with non-polar solvents such as isooctane (O'Malley 2010, p. 6). This level of solubility ensures that these varnishes can be safely removed without damaging the underlying paint layers.

Comparison of Dammar, MS2A and Regalrez 1094 Resin Varnishes

Oil paintings are complex materials composed of a mixture of organic and inorganic compounds. Analytical methods are applied not only to characterize the materials used by ancient painters, but also to investigate the state of deterioration and deterioration processes, and finally to plan and monitor the best conservation-repair practices (Casoli, 2012, p. 107).

Before starting the UV aging process, resin varnishes were applied to the slides in the most common and most frequently applied combinations in the field of conservation. For each varnish group, the necessary combinations were adjusted according to their usage characteristics. During the application of the varnishes on top of each other, the most commonly used combinations in the field of conservation were chosen, both current and traditional. In addition, combinations that have no place in practical use, such as brush on air brush application, were eliminated as a result of examinations made before the application phase. Therefore, the combinations applied were based on the literature review and common applications.

Varnish combinations were applied on the slides in two coats, three coats and finally four coats, which were selected from the most common methods. The application of the varnishes was carried out in three main principles. For spray application, MAIMERI brand dammar varnish, which is the most frequently encountered in literature searches, was selected. For ease of application, dammar was applied through the spray nozzle and sprayed onto the slides to form a homogeneous layer. The liquid dammar solution was applied with a brush. This solution applied with a brush was prepared as 20% dammar/terebentin. The solution was mixed frequently with a metal stirrer in a glass container to ensure a homogeneous structure. The same proportion of the solution was filled into the chamber of the air brush for the coats applied with the air brush. At this stage of application with the air brush, it stands out with its economical consumption.

Another type of varnish, Regalrez 1094, which is a low molecular weight resin, was applied with the most common combinations as a result of literature searches. In the Regalrez 1094 varnish group, brush application on the air brush was not included due to the lack of practical use. Regalrez 1094 resin varnish was applied two coats on top of each other on the resins in this group. For the solution applied with a brush, identical brushes of 1 cm in size and a clean brush that had not been used to apply other varnishes were used. Since the varnish in this resin group is not in spray form, Regalrez 1094 was placed on the slides only in liquid form with the help of a brush and an air brush.

The last type of varnish applied to the slides in certain combinations before UV aging is MS2A, a ketone resin varnish with a low molecular weight. Combinations belonging to this group were created after literature searches. In the laboratory environment where the combinations were grouped into sets, the accelerated artificial UV aging process was started after the required drying times were completed. In addition, one set for each resin group was kept in the laboratory without aging in order to compare the conditions before and after aging.

Based on the literature reviews, aging processes corresponding to 10-year and 20-year durations were applied, considering the average aging/degradation time of varnish as informed by the data obtained. To achieve the most standardized results without being affected by extreme environmental changes, the samples were conditioned in the environment for a period of approximately half an hour (Whitmore & Colaluca, 1995). For the second aging period of 20 years, an exposure time of 56 hours was selected. The temperature was maintained consistently within the average range for both the UV cabinet and the laboratory environment housing the cabinet.

The samples were examined before and after aging using visible light, ultraviolet light, and a light microscope. The visible light images of the samples were taken with a Canon EOS 600D 18-55 IS II digital camera in the laboratory environment. The shots were manually controlled, and ISO settings were adjusted according to the specific characteristics of the samples to complete the visual documentation. The images were taken at approximately 20-25 cm between the samples and the camera.

For ultraviolet imaging, the laboratory environment was isolated from natural and artificial light. UV imaging lenses were then attached to the Canon EOS 600D 18-55 IS II digital camera lens. The SEM scanning of varnish samples subjected to UV aging for 10 and 20 years was conducted using a Jeol NeoScope JCM-5000 device. Examination of the samples with a light microscope was performed at a constant magnification of X 2.0 for all three groups.

NMR and HR-MAS NMR spectroscopy are essential tools for examining the physico-chemical properties of both soluble and insoluble fractions of artificially aged materials and for directly analysing interactions that may occur in deteriorated paintings. NMR is a crucial analytical method for studying structural changes that can occur due to degradation processes such as oxidation, hydrolysis, and depolymerization. It is used not only to detect visible degradations in the artwork but also to identify potential degradations that may occur over time. In this study, a Bruker Avance III HD 400 MHz NMR spectrometer was used.

There are some general principles regarding airbrush application. A sample surface test area must be determined before application. All materials used must be recyclable and pH-neutral. The amount of liquid contacting the surface must be controlled, and the risk of dripping, splashing, and spreading must be eliminated. Airbrush and compressor systems must provide oil-free, filtered air.

The airbrush values used in the application are as follows;

- Air Pressure: 10-15 psi (0.7-1 bar)
- Nozzle Distance: 5-10 cm – suitable for localized applications
- Nozzle Diameter: 0.2-0.3 mm

Findings

The results are presented according to varnish type (dammar resin, MS2A ketone resin, and Regalrez 1094 hydrocarbon resin) and artificial aging duration (10 years and 20 years equivalent). Observations are based on visual inspection (VIS), ultraviolet fluorescence (UVF), light microscopy, SEM imaging, and NMR analysis.

Dammar Resin Varnish

10-Year Artificial Aging

Surface degradation was characterized by blistering, cracking, and localized loss of varnish integrity. Samples with brush-applied dammar over spray-applied retouching varnish exhibited large surface discontinuities and groove-like cracks. Airbrush-applied top layers showed alligator-type cracking patterns, whereas fully brush-applied samples displayed smaller blisters and localized swelling but retained overall structural stability.

20-Year Artificial Aging

Extended UV exposure intensified microcracking and surface roughness, particularly in brush-applied layers. Tree root-like crack networks became prevalent, and some samples exhibited material detachment, deep fissures, and uneven surface morphology. However, brush-then-airbrush applications demonstrated comparatively higher structural cohesion than other combinations.

MS2A Ketone Resin Varnish

10-Year Artificial Aging

MS2A varnish samples displayed surface fragmentation, blistering, and concave–convex deformations. Fully spray-applied layers exhibited local crack networks and abrasions, while brush applications showed deeper cracks and textural disruptions. Mixed application methods tended to result in perforations and interlayer separation.

20-Year Artificial Aging

Degradation processes observed at 10 years were more pronounced. Increased porosity, granular surface textures, and loss of elasticity were common. Spray-applied layers developed hollow blister formations due to burst air pockets. Brush-airbrush combinations exhibited better preservation of surface integrity, with only minor blistering and additional deposits. In some airbrush applications, no major structural failures were detected, even after 20 years.

Regalrez 1094 Hydrocarbon Resin Varnish

10-Year Artificial Aging

Regalrez 1094 demonstrated the highest stability among the tested resins. Most samples maintained their structural integrity with minimal degradation. Only localized blistering and minor surface roughness were observed in certain spray-based combinations. Brush applications generally resulted in consistent, uniform varnish films.

20-Year Artificial Aging

The stability observed at 10 years persisted, with minor increases in blister formation and occasional fine cracking. Brush-applied layers remained largely intact, while spray-applied layers exhibited localized swelling. In four-layer brush applications, the varnish continued to display excellent cohesion, suggesting a strong resistance to UV-induced deterioration.

NMR Analysis Findings

NMR spectroscopy confirmed that the physical degradation observed in SEM imaging was accompanied by chemical alterations.

- **Dammar Resin:** Increased oxidation and polarity changes, consistent with advanced autoxidation processes.
- **MS2A Resin:** Evidence of depolymerization, oxidation, and reduced solubility, correlating with loss of mechanical resilience.
- **Regalrez 1094:** Minimal chemical alteration detected, supporting its superior aging stability observed in physical examinations.

Discussion

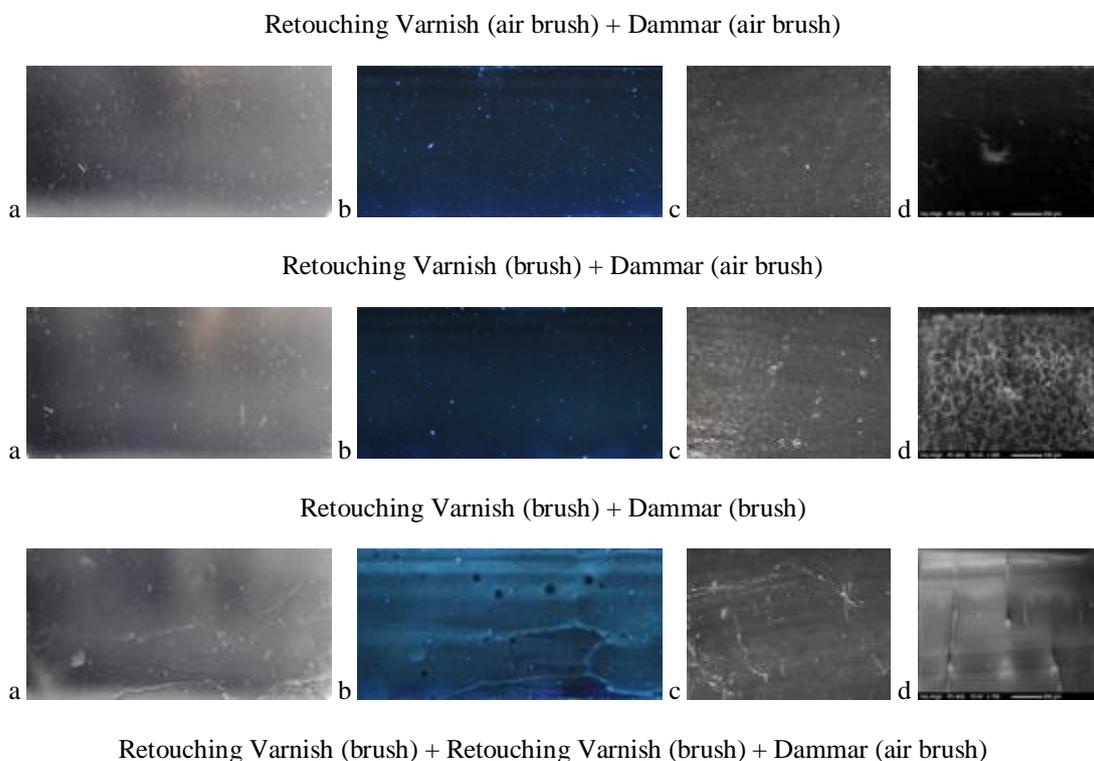
Analysis of Dammar Resin Varnish After 10 Years of Artificial Aging

In the *Figure 1*; after the aging process, the relatively large holes formed on the surface of the dammar varnish, which was applied with a brush over the two coats of spray-applied dammar varnish, prevented the varnish from remaining uniform on the surface. Similarly, in the varnish coating where the first two retouching varnish layers were applied with a brush, and the final dammar varnish layer was applied with an air brush, a wide crack was observed over a large area contrary to the general texture, forming a long thin groove as the two parts separated. At the points where the varnish integrity was compromised, both bulging outwards forming a mouth-like structure and deepening inward as the material receded were detected. In the sample where spray-applied dammar varnish was applied over brush-applied retouching varnish layers, blisters were observed on the surface integrity after the aging process. It was observed that the varnish material thinned due to the aging effect on the lam and blisters appeared sporadically. These blisters, which were smaller in size and more numerous than the previous two samples,

managed to remain relatively stable on the varnish surface. In the sample where two layers of retouching varnish and two layers of dammar resin varnish were applied, all layers were applied with a brush. Small blisters and minor tears were observed on the varnish surface. However, there was no general separation in the varnish texture. In the sample where both the first two retouching varnish layers and the final dammar resin varnish layer were applied with a brush, additional formations were observed on the surface. It also exhibited bubble-like swelling characteristics, albeit sparsely and in small numbers. However, compared to the blisters observed after the 10-year aging of the previous samples, it remained quite stable and consistent.

As a result of the aging process applied to the sample of dammar resin varnish sprayed with an air brush over the brush-applied retouching varnish, surface undulations, separated regions, and small particle formations were observed. Micro-cracks, though in small amounts, occurred because of aging. The aging process applied to the dammar resin varnish with the air brush over the spray-applied retouching varnish resulted in crack patterns like alligator cracking. On the slide where two layers of retouching varnish were applied by spray and dammar varnish by air brush, cracks of varying sizes and structures were observed on the sample surface. Cracks of different sizes, depths, and lengths within the material's structure occasionally intensified the appearance of alligator cracking. Although the cracks were smaller in size compared to the previous two samples, they were more numerous. In the sample where two layers of spray-applied retouching varnish were followed by a layer of brush-applied dammar varnish, cracks occurred due to the micro-fragility. Besides these small, almost microscopic cracks, additional formations were observed due to aging. No significant change was observed on the surface of the dammar varnish applied with a brush over the retouching varnish applied with a brush. Aside from the sparse and small additional formations on the surface, the degradation did not significantly affect the surface.

Figure 1: Images of Dammar Resin Varnish Samples Aged for 10 Years; a) Examination with Visible Light (VIS), b) Examination with Ultraviolet (UV) Light, c) Examination with Light Microscope, d) Examination with SEM





Retouching Varnish (brush) + Retouching Varnish (brush) + Dammar (brush)



Retouching Varnish (brush) + Retouching Varnish (brush) + Dammar (brush) + Dammar (brush)



Retouching Varnish (brush) + Retouching Varnish (brush) + Dammar (spray)



Retouching Varnish (spray) + Dammar (air brush)



Retouching Varnish (spray) + Dammar (brush)



Retouching Varnish (spray) + Retouching Varnish (spray) + Dammar (air brush)



Retouching Varnish (spray) + Retouching Varnish (spray) + Dammar (brush)



Source: (Dallik, 2022 Figure 1)

Analysis of MS2A Resin Varnish After 10 Years of Artificial Aging

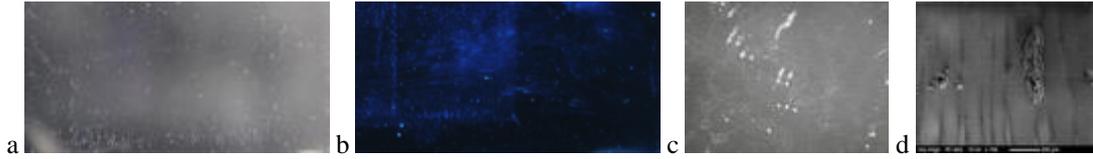
In the *Figure 2*; because of the aging process applied to the sample where two layers of retouching varnish were applied with a brush and the MS2A varnish was applied as a spray, regional texture differences were observed due to inequality between the layers and deterioration in the varnish. Blistering and swelling of various sizes were encountered. On the surface of the sample where both the retouching varnish layer and the final varnish layer were applied with a brush, the aging process sensitized the surface resistance, resulting in a deep crack corresponding to the thickness of the varnish layers. The material showed fragmentation on the slide due to aging and separation, resulting in a loss of structural integrity. In the sample where two layers of retouching varnish were applied with a brush and one layer of MS2A ketone varnish was applied with a brush, degradation types leading to hole formation due to loss of textural integrity were observed. The material deformed and swelled with aging, resulting in punctures due to the loss of elasticity, leading to fragmented surfaces. With the application of two layers of MS2A varnish with a brush over two layers of retouching varnish, a particle-like structure developed on the surface texture due to aging. The varnish material could not maintain its integrity, resulting in a surface that was both concave and convex. After the degradation of the slide where two layers of retouching varnish were applied with a brush followed by two layers of MS2A spray ketone varnish, the varnish resin could not maintain inter-layer integrity. In the sample where two layers of retouching varnish were applied as a spray and the final layer of MS2A varnish was applied with a brush, large layer cracks and separations were observed. The material exhibited a tendency to swell due to the degradation effect. In the sample where two layers of retouching varnish were applied as a spray followed by two layers of MS2A ketone varnish applied with a brush, the four-layer varnish structure underwent degradation, resulting in rare hole formations on the surface. An increase in deformed structures and perforated deformation was observed. Surface abrasions were observed quite frequently.

In another sample, the first two layers consisted of retouching varnish, and the following two layers consisted of MS2A varnish. All four layers, applied as spray varnishes, tended to become rough after aging. Local network-like cracks were observed due to the aging effect. Although not very dense, these cracks resulted in wear and loss of integrity. After the aging process applied to the sample where two layers of retouching varnish were applied as spray and the final varnish, MS2A, was applied with an air brush, regional and micro-scale cracks were observed in the deterioration. It was seen that it was more resistant to crack formation compared to the previous sample. In the sample where the first two layers of retouching varnish were applied with a brush and the final varnish, MS2A, was applied with an air brush, swelling and cracking were sporadically observable after the aging process. These cracks, although very few, were relatively more durable compared to the previous two samples. The aging characteristics of the sample

applied on a slide with one layer of spray-applied retouching varnish and brush-applied MS2A ketone varnish showed that the surface maintained its overall integrity except for rare cracks and collapses, and few regional breaks. No cracking or separation was observed on the surface of the final varnish, MS2A, applied with an air brush over the spray-applied retouching varnish layer after aging.

Figure 2: Images of MS2A Ketone Resin Varnish Samples Aged for 10 Years; a) Examination with Visible Light (VIS), b) Examination with Ultraviolet (UV) Light, c) Examination with Light Microscope, d) Examination with SEM

Retouching Varnish (air brush) + MS2A (air brush)



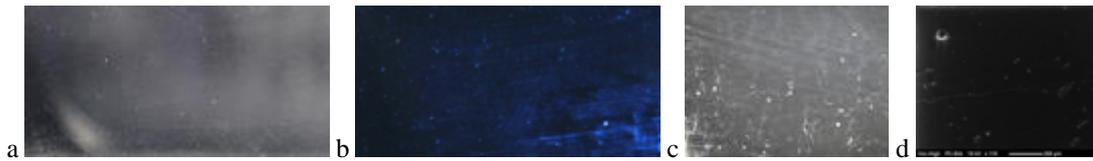
Retouching Varnish (brush) + MS2A (air brush)



Retouching Varnish (brush) + MS2A (brush)



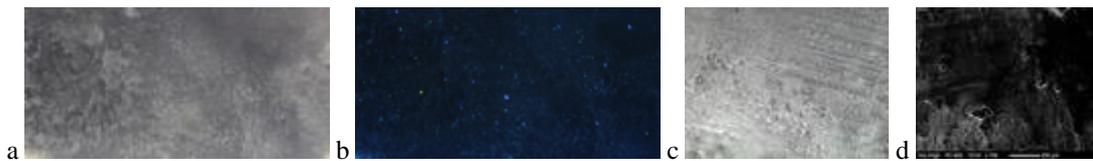
Retouching Varnish (brush) + Retouching Varnish (brush) + MS2A (air brush)



Retouching Varnish (brush) + Retouching Varnish (brush) + MS2A (brush)



Retouching Varnish (brush) + Retouching Varnish (brush) + MS2A (brush) + MS2A (brush)



Retouching Varnish (brush) + Retouching Varnish (brush) + MS2A (spray)



Retouching Varnish (brush) + Retouching Varnish (brush) + MS2A (spray) + MS2A (spray)



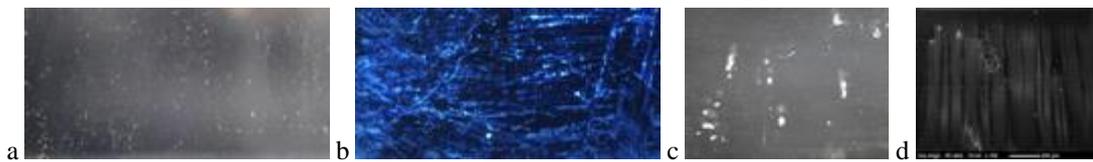
Retouching Varnish (spray) + MS2A (air brush)



Retouching Varnish (spray) + MS2A (brush)



Retouching Varnish (spray) + Retouching Varnish (spray) + MS2A (air brush)



Retouching Varnish (spray) + Retouching Varnish (spray) + MS2A (brush)



Retouching Varnish (spray) + Retouching Varnish (spray) + MS2A (brush) + MS2A (brush)



Retouching Varnish (spray) + Retouching Varnish (spray) + MS2A (spray)



Retouching Varnish (spray) + Retouching Varnish (spray) + MS2A (spray) + MS2A (spray)



Source: (Dallık, 2022, Figure 2)

Analysis of Regalrez 1094 Resin Varnish After 10 Years of Artificial Aging

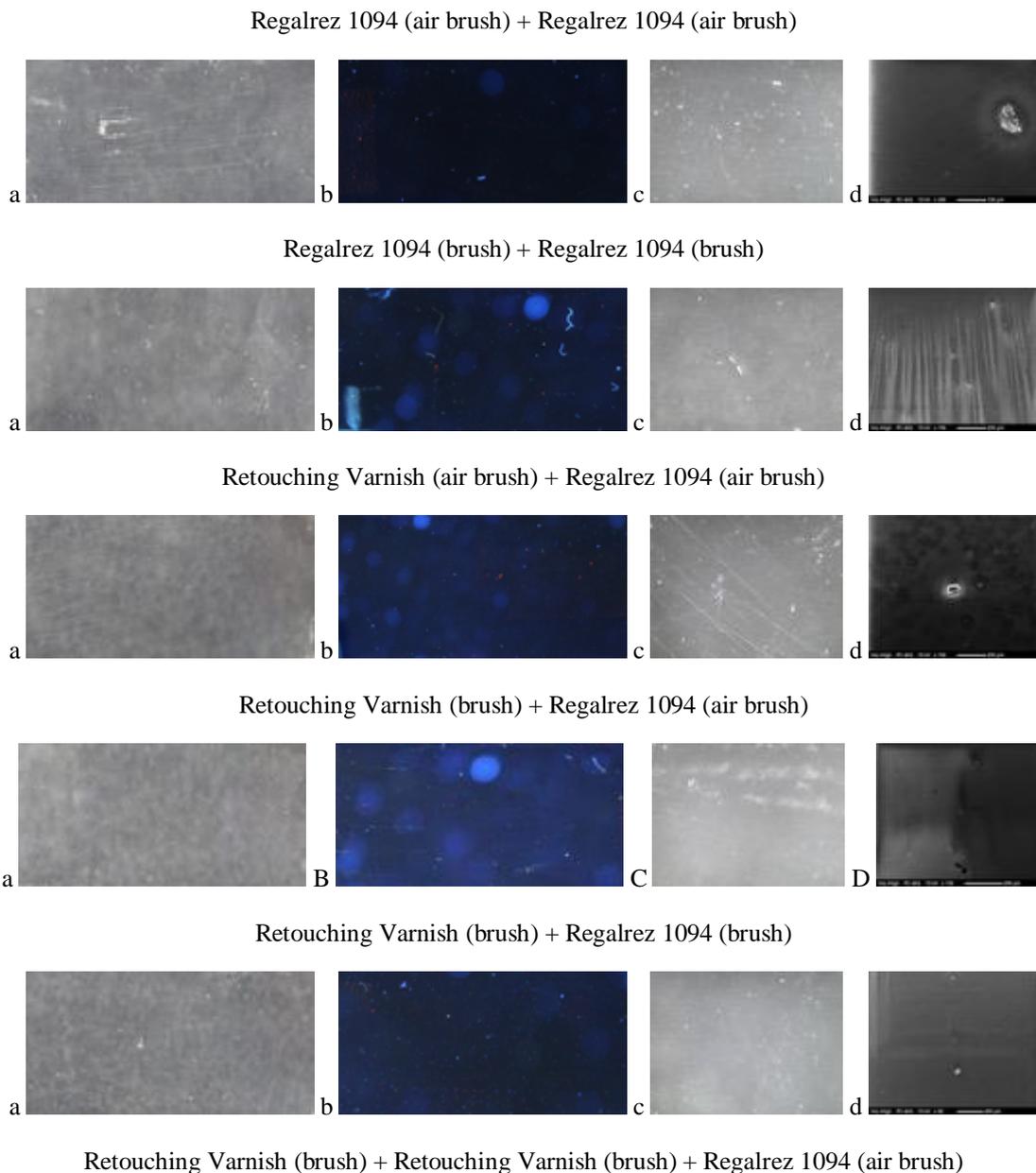
In the *Figure 3*; the sample applied on a slide with two layers using an air brush, it is observed that the initial varnish appearance is preserved after the aging process. In the sample where the first layer of retouching varnish and the final varnish, Regalrez 1094, were applied with a brush, no separation, detachment, or loss of integrity was observed on the surface after aging. In the sample where the first and second layers of resin varnishes were applied with a brush, the stable structure in surface stabilization continued despite deterioration. In the sample where Regalrez 1094 resin varnish was applied with an air brush on a spray retouching varnish layer, no abrasion or pitting was observed on the surface as far as could be read after aging. In the sample where the retouching varnish was applied with a brush and the Regalrez 1094 varnish was applied with an air brush, no deformed surface appearance was formed because of aging. No significant loss of resistance was observed in the varnish layer, and no deterioration was observed other than the formation of additional substances. In the sample where the first layer of retouching varnish was applied with an air brush and the second layer of varnish was also applied with an air brush, a granular-dotted structure developed on the varnish surface after aging, while the varnish continued to remain as a single piece. No abrasion or fragmentation was encountered in the varnish structure after 10 years of aging. In the sample where two layers of retouching varnish were applied with a brush and two layers of Regalrez 1094 varnish were applied with a brush, after 10 years of aging, it was observed that the overall and single structure of the varnish layer continued, but small-sized additional substance formations occurred.

After applying two layers of retouching varnish with a brush, one layer of Regalrez 1094 varnish was applied with a brush. After 10 years of aging, the varnish layer on the surface remained stable in its entirety. While it maintained its stable structure, small-sized and limited amounts of additional substance formations were observed. After these samples, the first one that underwent comparatively more degradation consists of two layers of retouching varnish applied with a brush and a third layer of Regalrez varnish applied with an air brush. It was observed that the sample developed surface appearances with different structures after aging. The sample, with the first two layers of retouching varnish applied with a brush and the final layer applied with an air brush, developed blistering as a form of degradation. These blistering lines, which are not observed everywhere, showed regional development and increased density in certain areas. Additionally, abrasions were found on the sample surface.

In the sample where the first and second layers of retouching varnish were applied as a spray and the Regalrez 1094 varnish was applied with an air brush, and subjected to 10 years of aging, a layered texture structure can be seen. The varnish surface exhibited images disrupting the overall homogeneous structure of the varnish layer, such as local cracking and roughness formation. In the sample where the final layer of retouching varnish was applied as a spray and the Regalrez 1094 varnish was applied with a brush,

a deformed surface was formed after aging. The underlying layer of retouching varnish applied as a spray was observed to blister and move upwards, causing surface deformations. In the three-layer sample, where the first two layers of retouching varnish were applied as a spray and the final layer of Regalrez 1094 varnish was applied with a brush, it was observed that uneven movements and surface (texture) differences occurred on the sample surface due to expansion between the varnish layers. Local blistering in the varnish caused cracks at points where elasticity met resistance. After the aging process, it was observed that the swollen areas caused collapses as the varnish material separated from the varnish structure.

Figure 3: Images of Regalrez 1094 Varnish Samples Aged for 10 Years; a) Examination with Visible Light (VIS), b) Examination with Ultraviolet (UV) Light, c) Examination with Light Microscope, d) Examination with SEM





Retouching Varnish (brush) + Retouching Varnish (brush) + Regalrez 1094 (brush)



Retouching Varnish (brush) + Retouching Varnish (brush) + Regalrez 1094 (brush) + Regalrez 1094 (brush)



Retouching Varnish (spray) + Regalrez 1094 (air brush)



Retouching Varnish (spray) + Regalrez 1094 (brush)



Retouching Varnish (spray) + Retouching Varnish (spray) + Regalrez 1094 (air brush)



Retouching Varnish (spray) + Retouching Varnish (spray) + Regalrez 1094 (brush)



Source: (Dallık, 2022 Figure 3)

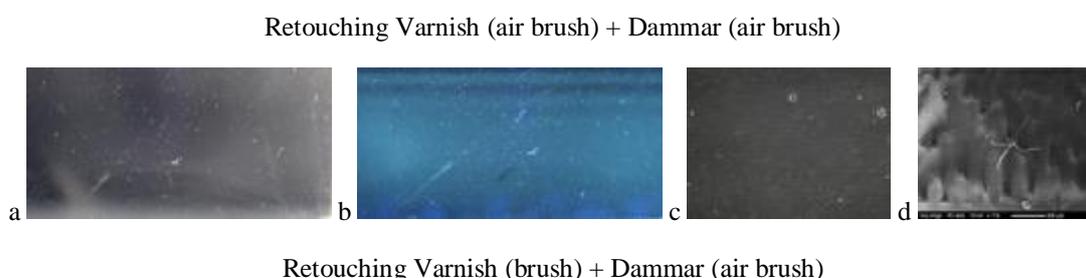
Analysis of Dammar Resin Varnish After 20 Years of Artificial Aging

In the *Figure 4*; Due to regional material losses, physical differences occurred on the surface of the sample, which consisted of a retouching varnish applied with a brush followed by a dammar resin varnish applied with an air brush. As a result of the degradation of the varnish, cracks and closely spaced fractures appeared. When compared with the same sample subjected to 10 years of aging, there was no increase in the formation of additional materials. In the sample where the dammar resin varnish was applied with a brush over the retouching varnish applied with a brush, after 20 years of aging, frequent and shallow cracks reminiscent of tree roots were observed over much of the surface. Additionally, surface irregularities were noted due to changes in the form of the material caused by degradation.

In the sample where the first two layers of retouching varnish and the final layer of dammar varnish were applied with a brush, significant changes were observed after 20 years of degradation. Stains and texture differences appeared in areas where the varnish degraded and evaporated from the surface. The tendency of the varnish to detach from the surface due to degradation resulted in cracks, fractures, and pitting. In the sample where two layers of retouching varnish were applied as a spray and the third layer of dammar varnish was applied with an air brush, subjected to an aging process to achieve 20 years of degradation, small cracks appeared after aging. During these material losses, the formation of deep fissures and the subsequent surface differences were observed. In the sample where the first two layers of retouching varnish were applied with a brush and the final layer of dammar varnish was applied with an air brush, additional formations and physical differences were also observed.

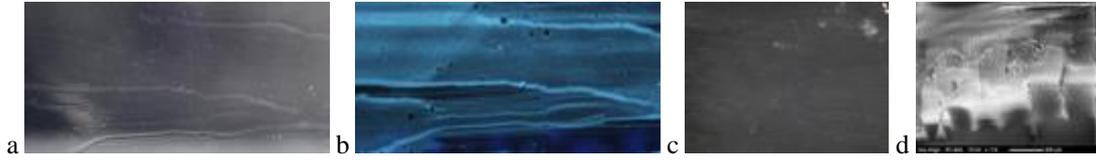
On the sample with two layers of varnish applied on a slide, where the first layer was retouching varnish applied with a spray and the second layer was dammar resin varnish applied with a brush, material agglomerations continued to develop in particles on the sample subjected to 20 years of aging. In the sample where both varnishes were applied with an air brush, extreme swelling and inability to maintain physical integrity due to regional blistering of the varnish after 20 years of aging resulted in ruptures. In the sample where dammar varnish was applied with an air brush over spray retouching varnish, it was observed that the surface structure continued to maintain its integrity. In the sample where the first two layers of retouching varnish were applied with a brush, followed by a final layer of spray dammar varnish, it was observed that the material became denser and tighter with small blistering, indicating that the material moved away from these blisters because of degradation. After the aging process of the sample where two layers of retouching varnish were applied as a spray and one layer of dammar varnish was applied with a brush, it was observed that the surface formed a flat but uneven structure. In the sample where two layers of retouching varnish and two layers of dammar varnish were applied, relatively less deformation was observed compared to 10 years of aging. When compared with 10 years of aging, micro crack networks were seen instead of speckled stains on the surface. Additionally, no general integrity-disrupting deteriorations such as splitting, detachment, or swelling were observed on the sample surface.

Figure 4: *Images of Dammar Resin Varnish Samples Aged for 20 Years; a) Examination with Visible Light (VIS), b) Examination with Ultraviolet (UV) Light, c) Examination with Light Microscope, d) Examination with SEM*





Retouching Varnish (brush) + Dammar (brush)



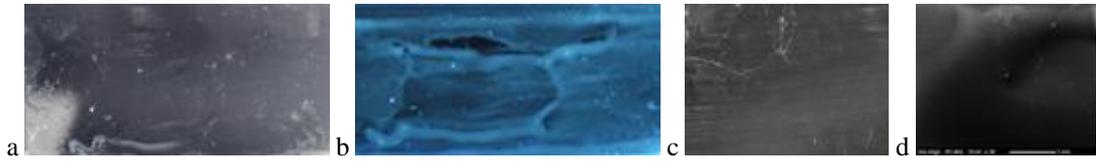
Retouching Varnish (brush) + Retouching Varnish (brush) + Dammar (air brush)



Retouching Varnish (brush) + Retouching Varnish (brush) + Dammar (brush)



Retouching Varnish (brush) + Retouching Varnish (brush) + Dammar (brush) + Dammar (brush)



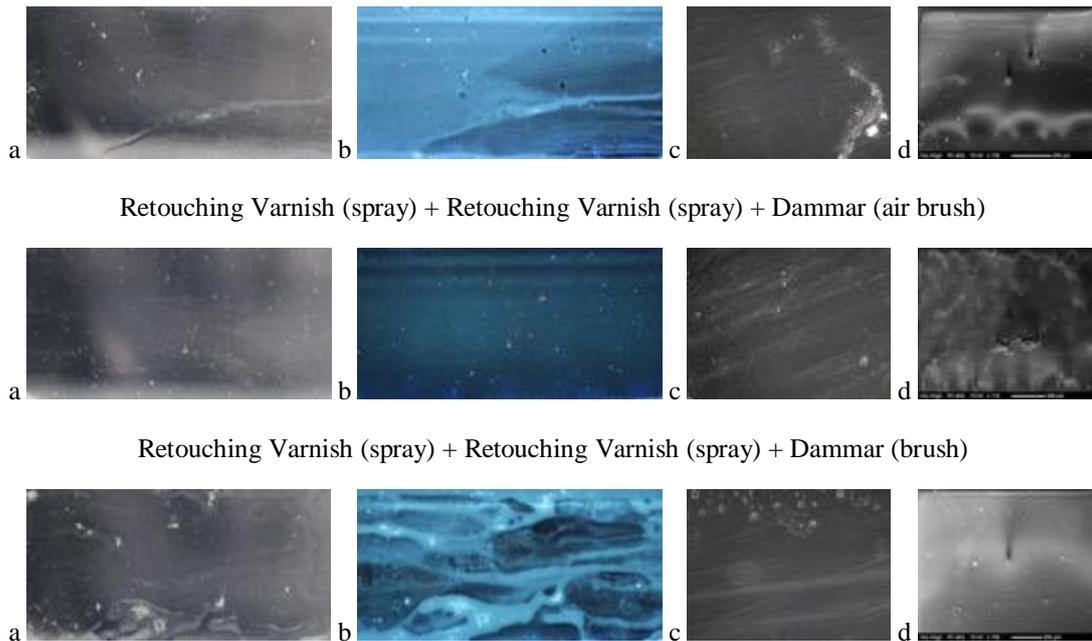
Retouching Varnish (brush) + Retouching Varnish (brush) + Dammar (spray)



Retouching Varnish (spray) + Dammar (air brush)



Retouching Varnish (spray) + Dammar (brush)



Source: (Dallık, 2022, Figure 4)

Analysis of MS2A Resin Varnish After 20 Years of Artificial Aging

In the *Figure 5*; The sample structure, where two layers of retouching varnish were applied with a brush and the final layer was MS2A varnish applied with a brush, showed noticeable textural differences. When compared with the same combination subjected to 10 years of aging, it was found that textural fragmentation increased, and the varnish material structure became more prone to roughness. As aging increased, it was observed that textural roughness also increased, making the material more susceptible to collecting dirt and dust. In the sample where two layers of retouching varnish and two layers of MS2A resin varnish were applied on a slide with a brush, the analysis revealed a highly fragmented, disrupted structure with significant surface irregularities due to differences in balance.

In the sample where the first two layers of retouching varnish were applied with a brush and the third and final layer of MS2A varnish was applied as a spray, concave-convex degradations were observed because of degradation examinations. It was observed that the two layers of retouching varnish applied with a brush and two layers of spray-applied MS2A ketone varnish formed a particulate, distinct, and porous structure. When compared to 10 years of aging, it was observed that the separations in its structure increased, and these separations became deeper. As a result of the 10-year and 20-year aging processes of the same sample, it can be inferred that as the duration of degradation increased, the varnish structure transformed into a particulate structure, moving away from its conservative function. Additionally, a significant increase in abrasion was observed in the 10-year sample. After 20 years of aging, with a single layer of spray retouching varnish followed by a final layer of brush-applied MS2A varnish, this sample also exhibited fractures, perforations in the varnish structure, and separations due to loss of strength between layers. This combination showed overall wear, moving away from its protective properties.

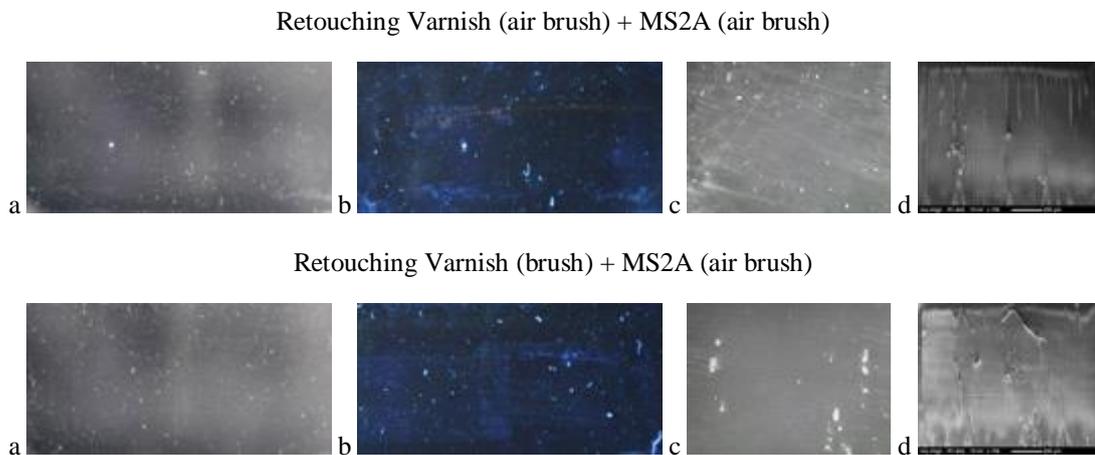
In the *Figure 5*; the sample where two layers of spray-applied retouching varnish were followed by a brush-applied MS2A varnish, perforations were observed. After aging, it was observed that the varnish layers swelled into bubbles, and these bubbles burst, creating hollow structures due to the release of the internal material. When compared to 10 years of aging, large-scale structural degradations transformed into smaller-scale degradations and became more frequent. In another sample where two layers of spray-applied retouching varnish were followed by two layers of MS2A ketone resin varnish applied with a brush, it was

found that perforations and wear increased after 20 years of aging, and the visual appearance of deformation in the texture increased. After 10 years of aging, the deformation was found to be perforated. In the sample where two layers of retouching varnish and the final layer of MS2A varnish were applied as sprays, the degradation characteristics observed were surface unevenness, the emergence of additional material, and cracking. Additionally, it was found that this differentiation acted as a catalyst, causing the varnish to lose its intended homogeneous and protective properties.

The sample, where two layers of retouching varnish were applied with a spray followed by MS2A varnish applied as a spray, experienced surface balance differences that caused swelling and weakened the varnish layer. Compared to the condition after 10 years of degradation, a reduction in its conservative properties was observed. In this combination, concave grooves formed at certain points, and the removal of materials from these areas resulted in voids. It can be inferred that no significant degradations were observed in the appearance of the sample, where retouching varnish and a ketone varnish type MS2A resin were applied with an air brush, after 20 years of aging. Small-sized additional formations were detected. The varnish generally remained at its original level, but volume loss was observed due to the effect of degradation. In the surface of the sample where retouching varnish was applied with a brush and MS2A varnish was applied with an air brush, no significant shape deformation was observed. In addition to maintaining its structural integrity, cracks, brittleness, and blistering occurred due to the effect of aging. It should be noted that an air brush application was used in both samples. In the sample where the first two layers of retouching varnish were applied with a brush and the final layer of MS2A varnish was applied with an air brush, no significant difference was observed when compared to the 10-year aging process; however, additional formations and small-sized blistering increased surface roughness. Overall, neither the 10-year nor the 20-year aged samples exhibited surface integrity loss. This sample also underwent an air brush application. Therefore, an air brush application can be shown as a common feature in all three samples.

On the surface of the sample, where one layer of retouching varnish was applied as a spray and the MS2A final varnish was applied with an air brush, and subjected to 20 years of degradation, no deformation that compromised the varnish's integrity was observed. Besides this, it can be said that the same sample maintained its stable and cohesive presence after the 10-year and 20-year aging processes corresponding to degradation. Finally, in the sample where two layers of retouching varnish were applied as a spray and the MS2A varnish was applied with an air brush, the surface integrity was preserved. Additionally, additional formations were observed because of the 20-year degradation process. When comparing the 10-year and 20-year aging processes of samples with the same combination, it can be inferred that the surface integrity was maintained in both aging periods.

Figure 5: Images of MS2A Ketone Resin Varnish Samples Aged for 20 Years; a) Examination with Visible Light (VIS), b) Examination with Ultraviolet (UV) Light, c) Examination with Light Microscope, d) Examination with SEM



Retouching Varnish (brush) + MS2A (brush)



Retouching Varnish (brush) + Retouching Varnish (brush) + MS2A (air brush)



Retouching Varnish (brush) + Retouching Varnish (brush) + MS2A (brush)



Retouching Varnish (brush) + Retouching Varnish (brush) + MS2A (brush) + MS2A (brush)



Retouching Varnish (brush) + Retouching Varnish (brush) + MS2A (spray)



Retouching Varnish (brush) + Retouching Varnish (brush) + MS2A (spray) + MS2A (spray)



Retouching Varnish (spray) + MS2A (air brush)



Retouching Varnish (spray) + MS2A (brush)



Retouching Varnish (spray) + Retouching Varnish (spray) + MS2A (air brush)



Retouching Varnish (spray) + Retouching Varnish (spray) + MS2A (brush)



Retouching Varnish (spray) + Retouching Varnish (spray) + MS2A (brush) + MS2A (brush)



Retouching Varnish (spray) + Retouching Varnish (spray) + MS2A (spray)



Retouching Varnish (spray) + Retouching Varnish (spray) + MS2A (spray) + MS2A (spray)



Source: (Dallık, 2022, Figure 5)

Analysis of Regalrez 1094 Resin Varnish After 20 Years of Artificial Aging

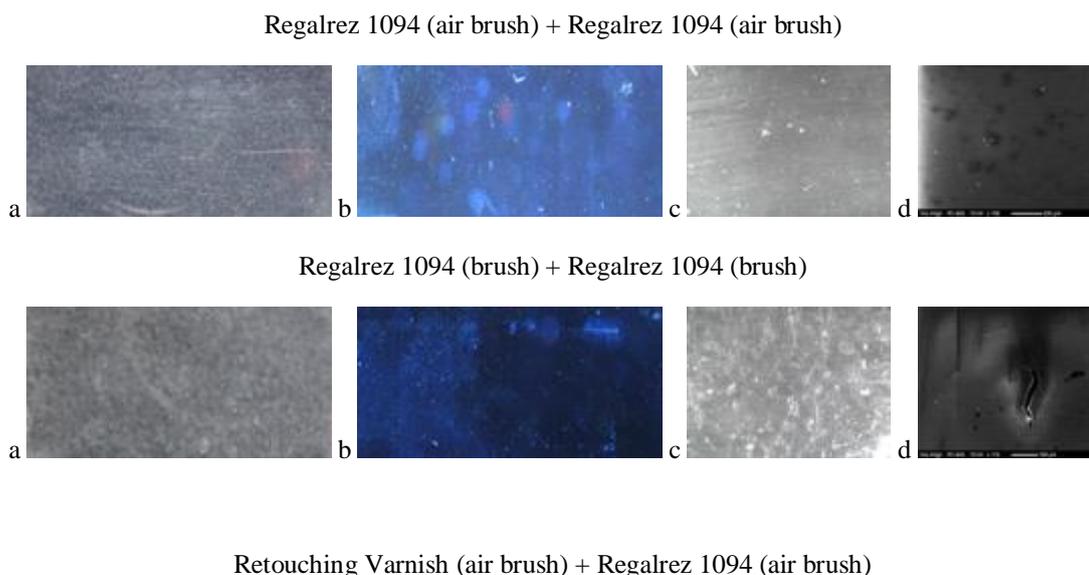
In the *Figure 6*; the sample, where two layers of Regalrez 1094 resin varnish were applied with an air brush, maintained its initial varnish appearance. After 10 years of aging, localized blisters were observed. Although it became more vulnerable to degradation, it can be said that it generally maintained its strength and remained stable. In this sample, where the first layer was retouching varnish applied with a brush, and the second layer was Regalrez 1094 varnish applied with an air brush, blisters formed because of degradation. In the sample where both layers were applied with an air brush, the first layer contained retouching varnish, and the second layer contained Regalrez 1094 varnish. It was observed that blisters

formed after aging, and the sample, when compared to the same sample subjected to 10 years of aging, continued to remain whole. In the sample, where the first layer of retouching varnish was applied as a spray and the final layer of Regalrez 1094 varnish was applied with a brush, it was observed that the varnish structure swelled, forming bubble shapes in some areas. When compared to the sample with the same combination subjected to 10 years of aging, it was observed that the swelling in the varnish continued. In the sample where two layers of retouching varnish were applied as a spray and the final layer of Regalrez 1094 varnish was applied with an air brush, blisters of varying sizes were observed. In both application methods, the common degradation characteristic of the samples was blistering formation. Although the blisters developed in different shapes and proportions in each sample, blister degradation was commonly observed.

The sample, where two layers of retouching varnish and Regalrez 1094 resin varnish were applied with a brush for all three layers, maintained its stability after the aging process, although small cracks started to appear in some areas. In the sample, where retouching varnish was applied as a spray and Regalrez 1094 varnish was applied with an air brush, granular additional materials were observed on the surface after aging. This sample, which is the only four-layer combination of this resin varnish, contains two layers of retouching varnish and two layers of Regalrez 1094 varnish, all applied with a brush. The varnish continued to maintain its stable structure. When compared with the 10-year aging process of the same sample, both samples continued to deteriorate in parallel.

In the Figure 6; the sample, where Regalrez 1094 varnish was applied with a brush over spray-applied retouching varnish, remained stable after the aging. After a 20-year aging period, no cracks or perforations were found in the varnish, which remained stable. In the sample, where two layers of Regalrez 1094 varnish were applied with a brush, a medium-sized crack was observed. Compared to the sample subjected to 10 years of aging, it was found that the varnish continued to remain stable, but cracks increased. In the sample, where two layers of retouching varnish were applied with a brush and the final layer of Regalrez 1094 varnish was applied with an air brush, the varnish's stable structure was maintained. The Regalrez 1094 varnish was applied with a brush over the retouching varnish applied with a brush. Thin cracks and perforations were observed on the surface.

Figure 6: Images of Regalrez 1094 Varnish Samples Aged for 20 Years; a) Examination with Visible Light (VIS), b) Examination with Ultraviolet (UV) Light, c) Examination with Light Microscope, d) Examination with SEM





Retouching Varnish (brush) + Regalrez 1094 (air brush)



Retouching Varnish (brush) + Regalrez 1094 (brush)



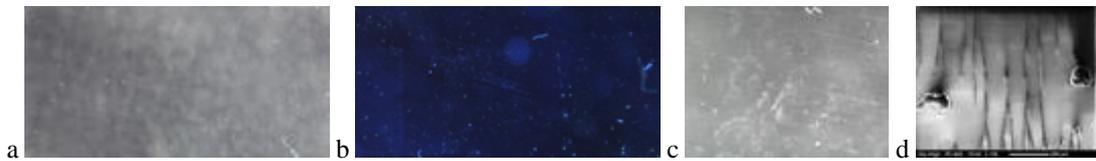
Retouching Varnish (brush) + Retouching Varnish (brush) + Regalrez 1094 (air brush)



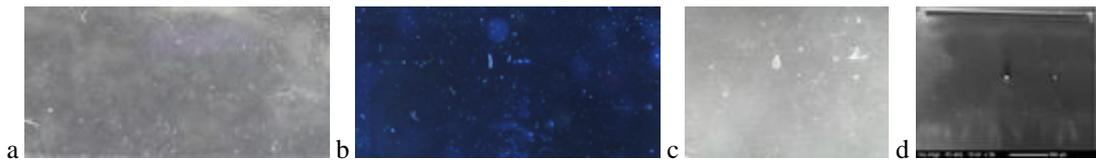
Retouching Varnish (brush) + Retouching Varnish (brush) + Regalrez 1094 (brush)



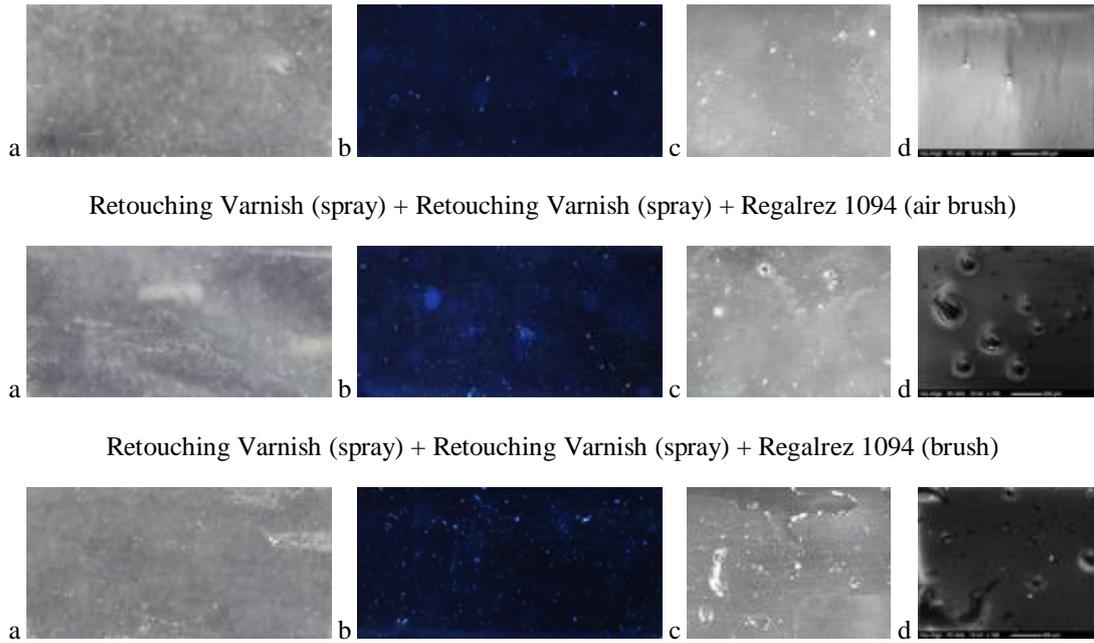
Retouching Varnish (brush) + Retouching Varnish (brush) + Regalrez 1094 (brush) + Regalrez 1094 (brush)



Retouching Varnish (spray) + Regalrez 1094 (air brush)



Retouching Varnish (spray) + Regalrez 1094 (brush)



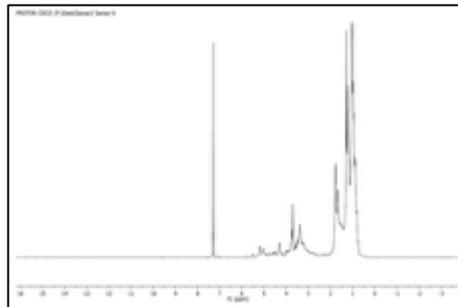
Source: (Dallık, 2022 Figure 6)

NMR (Nuclear Magnetic Resonance) Analysis Results

At this stage, analysis work has been initiated to elucidate the chemical degradation of the samples previously scanned with the SEM device. For NMR imaging, samples supporting the SEM analyses were selected to reveal the chemical dimension of the physical changes obtained. The samples selected among the types and groups of degradation for NMR imaging are as follows:

- Retouching Varnish (MS2A) + MS2A (20 years aging)
- Retouching Varnish (MS2A) + Retouching Varnish (MS2A) + MS2A (20 years aging)
- Regalrez 1094 + Regalrez 1094 (20 years aging)
- Retouching Varnish + Retouching Varnish + Dammar Varnish (20 years aging)

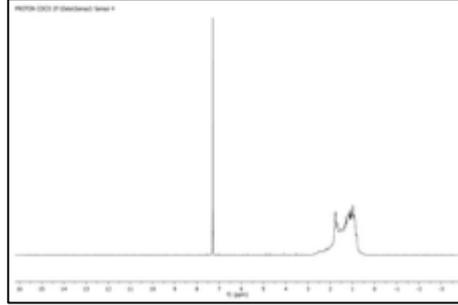
Figure 7: Retouching Varnish (MS2A) (brush application) + MS2A (brush application), 20 years aging



Source: (Boğaziçi Üniversitesi İleri Teknolojiler ARGE Merkezi, 2022 Figure 7)

According to the NMR analysis results of the sample containing 20-year-old aged MS2A varnish, the degradation structure manifested as depolymerization and oxidation.

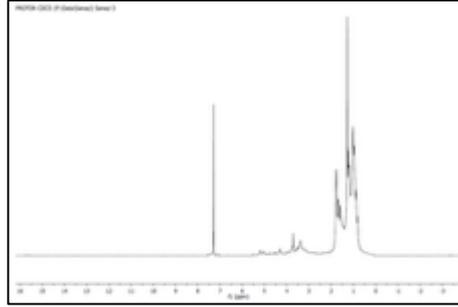
Figure 8: *Retouching Varnish (brush application) + Retouching Varnish (brush application) + Dammar Varnish (brush application), 20 years aging*



Source: (Boğaziçi Üniversitesi İleri Teknolojiler ARGE Merkezi, 2022 Figure 8)

When examining the NMR analysis graph of the sample with two layers of retouching varnish and a layer of dammar varnish, degradations supporting the SEM degradation results are observed. In the graph, where additional material formations are defined not only physically but also chemically, oxidation and increasing polarity rates can also be detected.

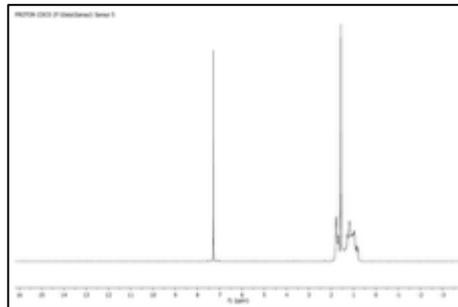
Figure 9: *Retouching Varnish (brush application) (MS2A) + Retouching Varnish (brush application) (MS2A) + MS2A (brush application), 20 years aging*



Source: (Boğaziçi Üniversitesi İleri Teknolojiler ARGE Merkezi, 2022 Figure 9)

The NMR analysis results of the sample, where MS2A resin was used as a retouching varnish and applied in a total of three layers, present the chemical structure and degree of degradation in the varnish. The data in the graph obtained from the analysis show that the chemical aging in the varnish structure reflects changes not only physically but also chemically.

Figure 10: *Regalrez 1094 (brush application) + Regalrez 1094 (brush application), 20 years aging*



Source: (Boğaziçi Üniversitesi İleri Teknolojiler ARGE Merkezi, 2022 Figure 10)

When examining the data obtained from the aging of the two-layer Regalrez 1094 varnish, it was found that, in addition to physical deformation, it also underwent chemical deformation, and these deformations exhibited parallelism.

Conclusion

This study comparatively evaluated the long-term stability and degradation patterns of three varnish types widely used in oil painting conservation: dammar resin, MS2A ketone resin, and Regalrez 1094 hydrocarbon resin. Using accelerated UV aging protocols equivalent to 10 and 20 years of natural exposure, physical and chemical changes were systematically documented through VIS and UV imaging, light microscopy, SEM, and NMR spectroscopy.

The findings demonstrate that Regalrez 1094 exhibited the highest stability under prolonged UV exposure, maintaining both structural integrity and chemical composition with minimal degradation. Dammar resin, while historically well-established in conservation practice, displayed moderate susceptibility to oxidation and physical cracking, particularly under extended aging. MS2A resin showed the greatest vulnerability to aging, with notable surface fragmentation, increased porosity, and chemical breakdown, especially in spray-applied configurations.

Application method significantly influenced varnish performance. Brush applications generally provided superior cohesion, reduced blistering, and improved overall film stability compared to spray applications. Hybrid techniques, such as brush followed by airbrush, also showed favourable results in certain cases, particularly for dammar varnish.

From a practical conservation perspective, these results suggest that Regalrez 1094, especially in brush-applied form, offers the most reliable long-term protection among the resins tested. However, the choice of varnish should also consider the artwork's specific material composition, environmental exposure, and reversibility requirements. The documented degradation profiles provide conservators with empirical reference data to anticipate material behaviour and make informed treatment decisions. Such studies would further enhance predictive models for varnish aging and contribute to evidence-based conservation strategies.

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