Advances in Science and Technology Research Journal

*Advances in Science and Technology Research Journal* 2024, 18(3), 14–20
https://doi.org/10.12913/22998624/185463
ISSN 2299-8624, License CC-BY 4.0

Received: 2024.01.11
Accepted: 2024.02.27
Published: 2024.04.20

# Testing of the Light Transmittance of Industrial Varnishes

Wojciech Żyłka[1*], Piotr Potera[1]

[1] College of Natural Sciences, Institute of Materials Engineering, University of Rzeszow, ul. Pigonia 1, 35-310 Rzeszów, Poland

* Corresponding author's e-mail: wzylka@ur.edu.pl

## ABSTRACT

The article presents the study of the light transmittance of a colorless car varnish. The varnish was tested at different temperatures for UV light transmission and the ability to protect car paint pigments from degradation. These tests make it possible to assess the durability and quality of the varnish. A comparison of light transmittance through glass, quartz glass and solar glass was made. It has been noted that the curing temperature of the varnish has an impact on its transmission (up to a few percent). A similar effect has been observed in the case of varnish with a hardener.

**Keywords:** light transmittance, varnishes.

## INTRODUCTION

One of the main causes of the degradation of paint coatings is the destructive effect of UV radiation, also observed for many other materials [1, 2, 3]. This radiation leads to the breakdown of chemical bonds in the binders and reduces their strength parameters. As a result of bond degradation in the coating, free radicals may also appear, which act as activators for further bond breakdown. The progressing degradation of the binder manifests as so-called "chalking" of the coating, wherein a lighter deposit of loosely bound mineral fillers appears on the surface of the coating. This process is inevitable, and practically every coating undergoes such degradation. To extend this period as much as possible, substances are used in industries such as the automotive industry, which act as UV filters. Depending on their structure, these substances may either absorb UV radiation and dissipate it in the form of heat energy (known as UV absorbers) or capture the free radicals formed in the coating and deactivate them (known as HALS-type substances). Typically, for better protection of the coating, appropriate mixtures of both types are used. Light transmittance is an important parameter affecting the durability of the paint coating. It is important how long the paint retains its light transmittance in the presence of UV radiation and changing atmospheric conditions such as humidity and temperature. UV (ultraviolet) radiation is a type of electromagnetic radiation with shorter wavelengths than visible light but longer than X-rays. UV is divided into three main categories: UV-A (320–400 nm), UV-B (280–320 nm), and UV-C (100–280 nm). The most harmful to health is UV-C, but most UV-C radiation is absorbed by the Earth's atmosphere and doesn't reach the surface. The primary source of UV radiation is the Sun, but UV is also produced by UV lamps used in medicine, industry, hygiene, and other fields. UV affects car paint, especially if the paint is not adequately protected. UV radiation can cause fading of the car's paint color by damaging the pigments and dyes in the paint, making the paint appear dull or lose its gloss. This effect is particularly noticeable on metallic paints, which may lose their metallic effects. UV radiation can also accelerate the degradation process of the paint, leading to cracking, peeling, and the formation of micro-cracks. This can result in rust or corrosion on the car's surface. The impact of UV on car paint is cumulative. This means that the longer a car is exposed to UV radiation, the more visible its effects will be. Therefore, protection against UV is essential for maintaining the quality of the paint over time. To shield car paint from UV exposure, a clear coat of paint is applied, which helps block UV light from reaching the deeper layers [4–8].

## Methods for measuring car paint layers

Currently, various methods are used to measure individual layers of car paints, even in forensic science, such as:

- fourier transform infrared spectroscopy (FTIR) is highly useful for the chemical characterization of samples and the aging processes of paint coatings [9]. Spectroscopy involves the study of matter's response to electromagnetic radiation. Electromagnetic energy can be divided into regions such as ultraviolet (UV), visible (VIS), and infrared (IR), among others, and based on this, spectroscopic methods can also be categorized [7]. The application of fourier transform infrared spectroscopy (FTIR) is recognized as one of the most effective techniques for studying and understanding surface chemistry [10];
- fourier transform infrared microspectroscopy (FTIR) integrates two investigative techniques: infrared spectroscopy and microscopy. This fusion enables precise analysis of chemical compounds within micro-areas of the examined material, encompassing biological specimens like yeast [11]. Beyond solely determining the sample's chemical composition, this method offers the possibility of scrutinizing the topography of chemical compounds present in the material under study [12]. Microspectroscopy finds application in the examination of automotive paints. It proves invaluable for analyzing the chemical composition and structural attributes of paint on a microscopic scale, using techniques such as micro Fourier-transform infrared spectroscopy (micro-FTIR) or Raman microspectroscopy, which facilitate the identification of paint constituents. This comprehensive analysis aids in determining pigments, binders, additives, and other substances used in the paint. Additionally, microspectroscopy allows for the scrutiny of the paint's microscale structure, encompassing layer analysis, micro-cracks, inclusions, and other intricate details, offering insights into both crystalline and amorphous structures. Moreover, it serves as a tool to detect paint defects, such as indications of corrosion, contamination, chemical alterations, or changes induced by environmental factors, notably UV radiation. Microspectroscopic studies contribute to assessing paint quality and durability, particularly useful in quality control assessments and understanding external factors' impact on paint. Its precision in analyzing specific paint areas is instrumental in qualitative research, monitoring aging processes, or diagnosing issues pertaining to automotive paint;
- Py-GC-MS (pyrolysis gas chromatography) is an analytical method in which small amount of organic complex molecules – samples – are broken down by heat to gaseous products and then separated on a chromatographic column and detected in a mass spectrometer [4]. In the Py-GC/MS method, the first stage involves the pyrolysis process, where complex chemical compounds, under high temperatures, break down into simpler volatile substances. In the second stage, these compounds are separated in a chromatographic column and identified in a mass spectrometer. The effectiveness of the Py-GC/MS method has been demonstrated in the analysis of car paints and spray paints for forensic purposes. The Py-GC/MS method can be successfully used as a complementary technique to FTIR spectrometry in cases where samples exhibit similar IR spectra, providing precise information about the chemical composition of the examined paint. The procedure has also been tested and successfully applied in the analysis of spray paints collected from building facades [13];
- SEM/EDX stands for scanning electron microscopy and energy-dispersive x-ray spectroscopy. Scanning electron microscopy is utilized when larger magnifications are required. SEM generates an image using a focused beam of electrons. SEM coupled with EDX utilizes X-ray radiation produced during the interaction of the electron beam with the sample to identify elements within the specimen. SEM/EDX is a non-destructive method and proves valuable when prior analyses do not yield conclusive results [4]. These methods are successfully employed for paint analysis [14, 15, 16].

## Car varnishes

The paint coat of automobile is composed of many layers. A new car has about 3–6 layers, a renovated car could have even more than 10 layers [8]. The production of original automotive paints involves a combination of used pigments and applied technology. Often, the difference in paints boils down to the effects created using specially selected pigments. Some paints may change color depending on the viewing angle, while others provide shine and gloss in sunlight. Additionally, there are those that exhibit subtle depth and luster. Increasingly, paint compositions include components such as volcanic rock (mica) or Xirallic, which, when added to the resin, are responsible for a unique shine and color intensity. Xirallic is currently used in many light-colored car paints, comprising aluminum oxide coated with a metal oxide. Clear automotive coatings, also known as clearcoats or clear finishing layers, are special types of paints used as the final layer in car painting. Their primary purpose is to protect and add gloss to the underlying paint while safeguarding against weather conditions, UV radiation, and scratches. They are a significant component in the painting and maintenance process of automobiles, helping to preserve their appearance and value for many years.

Types of clear automotive coatings, also known as clearcoats, can be categorized based on their chemical composition and technical characteristics:

a) based on chemical composition:
- acrylic-based clearcoats: Utilize acrylic resins as a primary component, known for good durability and flexibility;
- polyurethane-based clearcoats: Employ polyurethane resins, characterized by high durability, hardness, and resistance to abrasion;
- epoxy-based clearcoats: Utilize epoxy resins, providing exceptional chemical and mechanical resistance;

b) categorized by technology:
- traditional clearcoats: Conventional clear coatings applied using traditional painting methods;
- ceramic clearcoats: Incorporate ceramic nanoparticles for additional protection against scratches, corrosion, and UV radiation;
- hybrid clearcoats: Combine characteristics of different types of coatings, such as blending acrylic clearcoat properties with the durability of polyurethane;

c) based on visual effects:
- metallic clearcoats: Contain metallic particles, giving the coating a glossy and depth-enhancing effect;
- pearlescent clearcoats: Comprise pearlescent particles that provide a subtle shine and color-shifting effect depending on the angle of light;
- special effect clearcoats (e.g., chameleon): Exhibit changing colors based on the viewing angle.

## Measurement setup and instruments

The tested object was a clear varnish applied to quartz glass. A clear acrylic varnish with enhanced scratch resistance was applied to the surface of quartz glass. This varnish is known for its excellent spreadability, quick drying time, and the ability to create a glossy and highly durable coating. Its composition includes a blend of butyl acetate, xylene, 1-methoxy-2-propyl acetate, petroleum, light aromatic hydrocarbons, ethylbenzene, phenylethane, and post-reaction mass. Some of its key physical and chemical properties include a boiling point of 120–150 °C, autoignition temperature of 435 °C, density of 1g/cm3, and an odor threshold of 0.9–9 mg/m3 for xylene. The light transmittance of the paint was tested using a Cary 5000 spectrophotometer (Fig. 1).

The Cary 5000 spectrophotometer is a double-beam spectrophotometer. The light beam regulated by the slit falls on the Littrow monochromator (two diffraction gratings of 1200 lines/mm in the UV-Vis range). The light source in the Cary 5000 spectrometer is a tungsten halogen lamp (visible and infrared light) and a deuterium lamp (UV) with a quartz window. The used spectral range for a deuterium lamp is 175 nm–375 nm, while for a halogen lamp the range is from 375 nm to 3300 nm. A high-performance R928 photomultiplier was used as a UV-Vis detector, and as an NIR detector: an electrothermally controlled sulphide photocell with PbSmart technology ensuring better noise and linear parameters than standard photocells. To ensure low noise levels and minimize environmental influences, an optical isolation system is used. Agilent Cary 5000 Series UV-Vis-NIR Spectrophotometers are manufactured under an ISO 9001 certified quality management system. These guaranteed specifications are based on a statistical confidence level of ± 4 sigma of final acceptance testing performed in the factory.

## Light transmittance measurements

The research commenced with a comparison of light transmittance among glass, quartz glass, and solar glass. Subsequent tests were conducted on colorless varnish applied to a quartz glass plate, both with and without the addition of a hardener. The next stage of the study involved analyzing

**Figure 1.** Cary 5000 spectrophotometer

the influence of ambient temperature on the light transmittance of the varnish on a quartz glass substrate. Identification of object parameters:

a) comparison of light transmittance of glass, quartz glass and solar glass – the light transmittance results of the tested glasses are shown in Figure 2 below. Analyzing the research results (Fig. 2), one can observe distinct differences in the short-wave absorption edge among the transmission spectra of regular, solar, and quartz glass. In the case of the investigated regular and solar glass, the short-wave absorption edge lies around 300 nm, typical for soda-lime glass [17]. However, for quartz glass, it is significantly shifted towards the shorter wavelengths (below 180 nm [18], beyond the measurement range of the spectrometer). Therefore, quartz glass was chosen for the analysis of paint coatings due to its excellent transparency in the ultraviolet region.

b) light transmittance tests of colorless varnish applied to a quartz glass plate without and with the addition of a hardener – the obtained research results are illustrated in Figure 3. Applying varnish, and varnish along with a hardener, onto quartz glass leads to a decrease in transmission and the appearance of absorption edges around 370 nm. Due to the high transmittance of quartz glass in this spectral range, the absorption edge should be associated with the applied layers.

c) analysis of the impact of ambient temperature on the light transmittance of paint on a quartz glass substrate – then it was decided to examine the influence of ambient temperature on the light transmittance of the paint on a quartz glass substrate. The effect of ambient temperature on the light transmittance of the clear paint without hardener is presented in Figure 4 and Figure 5.

Subsequently, the research continued by investigating the effect of ambient temperature on the light transmittance of varnish applied on quartz glass with a hardener. The obtained measurement results are presented in Figures 6 and 7. The heating temperature has an impact on the transmission spectrum of the varnish (T%), as depicted in Figure 7. The mechanism behind this effect can be quite diverse. The varnish expands or contracts based on temperature, influencing its appearance, texture, and, indirectly, its optical properties. Moreover, elevated

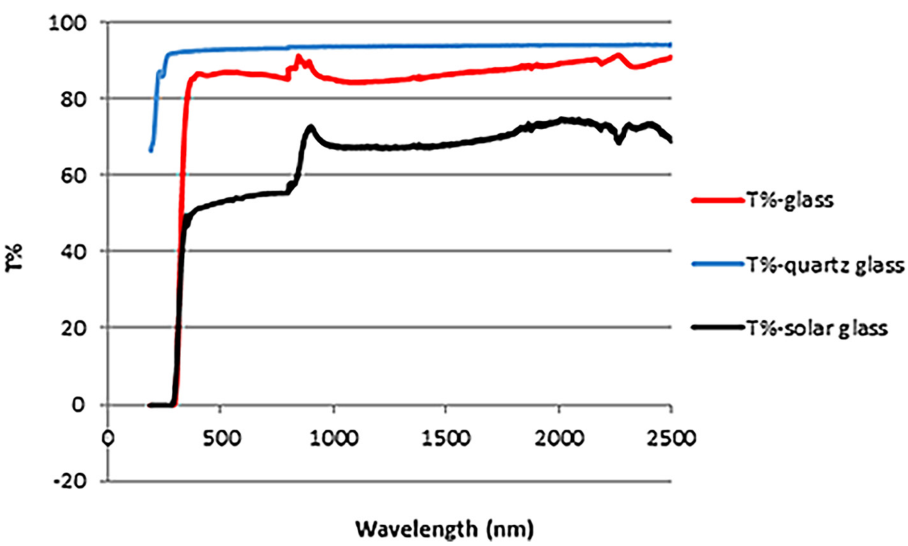


**Figure 2.** Comparison of light transmittance of glass, quartz glass, and solar glass

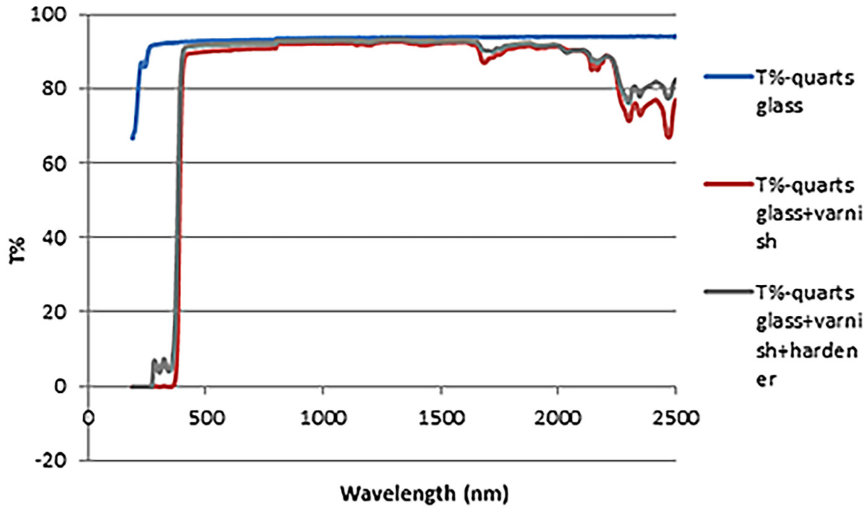


**Figure 3.** The effect of varnish coating and hardener on the light transmittance of a quartz glass substrate

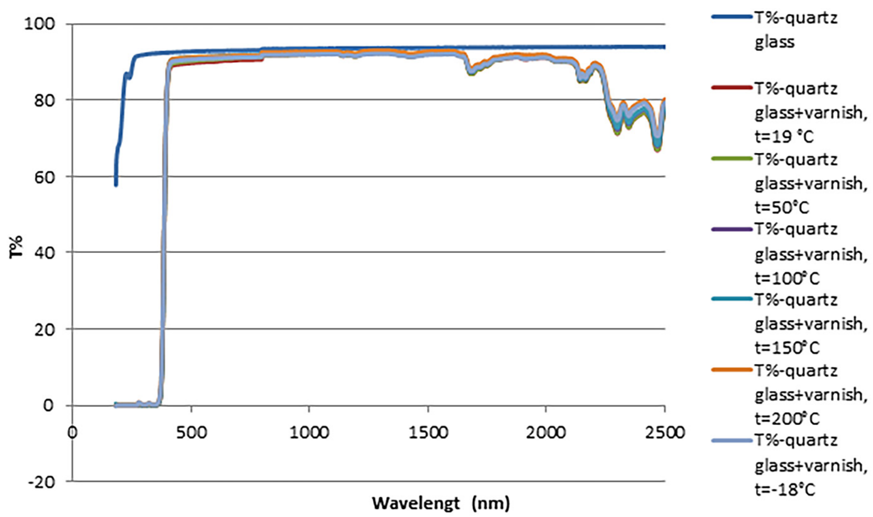


**Figure 4.** Study on the impact of ambient temperature on the light transmittance of clear varnish without hardener

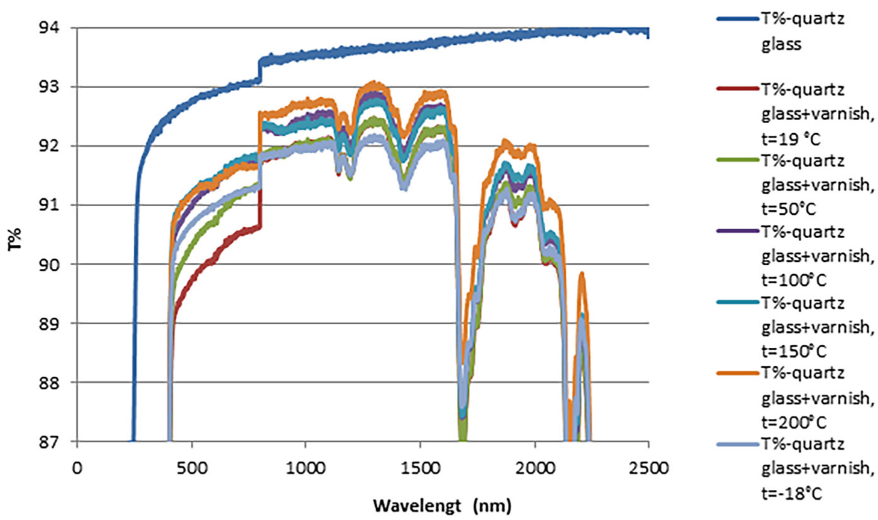


**Figure 5.** Study of the effect of ambient temperature on the light transmittance of clear varnish without hardener, transmittance range from 87% to 94%

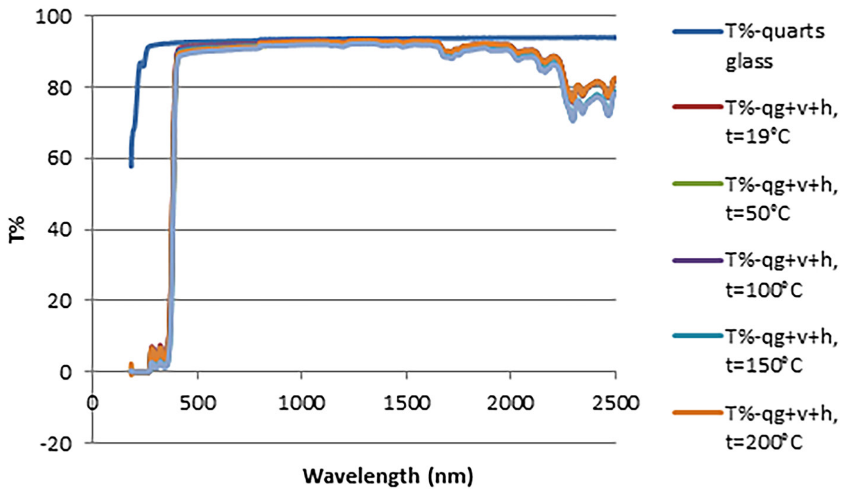


**Figure 6.** Study on the impact of ambient temperature on the light transmittance of clear varnish with hardener

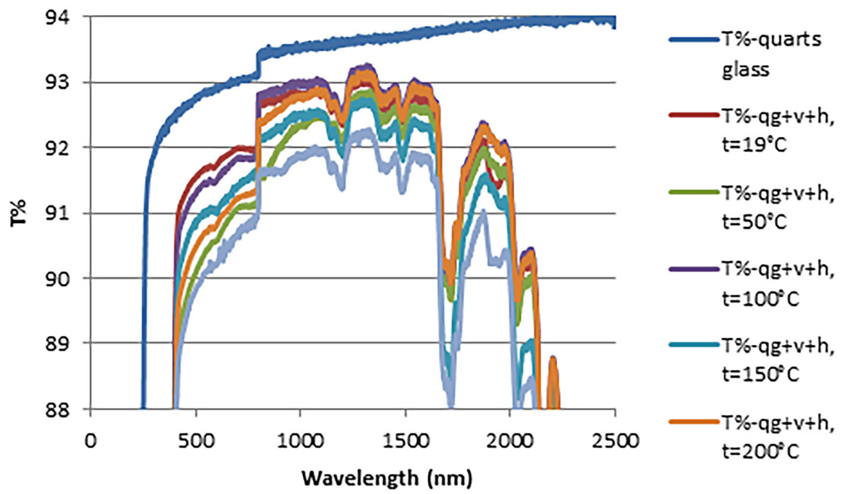


**Figure 7.** Study on the impact of ambient temperature on the light transmittance of clear varnish with hardener, transmittance range from 88% to 94%

temperatures result in alterations to its chemical structure and physical characteristics. Changes in temperature can also affect the matting effect, with the varnish appearing matte at lower temperatures and acquiring a shinier appearance at higher temperatures. Some clear varnishes may undergo color changes depending on temperature, likely due to light reflection differing based on the chemical structure of the varnish, subsequently affecting its transmission.

The varnish and varnish with a hardener start to transmit light around 370 nm and achieve full transmission around 410 nm, indicating that the absorption edge lies around 390 nm. Heating (within the temperature range up to 200 °C) and cooling to -18 °C result in slight (1–2%) changes in transmission values and minimal shifts in the position of the absorption edge for both varnish with and without a hardener. Both heating and cooling the coating to -18 °C lead, in the case of the varnish, to an increase in transmission in the visible range compared to room temperature. For the varnish with a hardener, the opposite phenomenon is observed, i.e., heating and cooling cause a decrease in transmission in the visible range compared to room temperature. In the transmission spectra of the varnish and varnish with a hardener in the infrared range, local transmission minima are visible around 1680 nm, 2145 nm, 2170 nm, 2300 nm, 2350 nm, 2465 nm, the values of which slightly depend on temperature. In the region above 2120 nm, the transmission decreases by several percent compared to the region with shorter wavelengths.

## CONCLUSIONS

Emanating from the work are the following conclusions. In the visible range, the transmission of both the varnish and the varnish with a hardener is significant and ranges between 89–92%. Heating (up to a maximum temperature of 200 °C) and cooling to minus 18 °C for both the varnish and the varnish with a hardener result in slight changes in transmission, a few percent, compared to room temperature. For the varnish, there is an increase in transmission, while for the varnish with a hardener, there is a decrease in transmission. Additionally, the edge of the fundamental absorption undergoes a minimal shift towards longer wavelengths for the varnish with a hardener and towards shorter wavelengths for the pure varnish at elevated and lowered temperatures. Therefore, the hardener plays an additional role in protecting the varnish from UV light at elevated and lowered temperatures. Observations indicate that the curing temperature of the varnish affects the viscosity of the coating. At higher temperatures, the varnish became more fluid.

## REFERENCES


1. Andrady A.L., Heikkilä A.M., Pandey K.K. et al. Effects of UV radiation on natural and synthetic materials. Photochem Photobiol 2023; 22: 1177–1202. DOI: 10.1007/s43630-023-00377-6.
2. Li Y., Jianlin F., Shaopeng W., Chen A., Dongliang K., Tao B., Yangming G., Zhang J., Li L., Wan L., Liu Q., Chen Z., Gu D. Review of ultraviolet ageing mechanisms and anti-ageing methods for asphalt binders, Journal of Road Engineering 2022; 2(2): 137–155. DOI: 10.1016/j.jreng.2022.04.002.
3. Remisova E., Briliak D., Evaluation of the Effect of Thermo-Oxidative Aging and UV Radiation on Asphalt Stiffness, Materials 2023; 16(10): 3716.
4. Milczarek J., Zadora G., Zieba-Palus J., Kościelniak P. Forensic examination of car paints 2008. Available from: https://www.researchgate.net/publication/294871293_Forensic_examination_of_car_paints
5. The Electromagnetic Spectrum [Internet]. Mini Physics 2018 [cited 5 September 2018]. Available from: https://www.miniphysics.com/electromagnetic-spectrum_25.html
6. Mohseni M., Ramezanzadeh B., Yari H. Effects of environmental conditions on degradation of automotive coatings. New trends and developments in automotive industry. India: Intech Open Access Publisher 2011; 267–96.
7. Vodišek T. Testing of the UV light effect on the automotive paints by FTIR spectroscopy. University of Split, University Department for Forensic Sciences / Sveučilište u Splitu, Sveučilišni odjel za forenzične znanosti. Master's thesis 2008.
8. Nieznańska J., Zieba-Palus J, Kościelniak P. Physico-Chemical study of car paints coats. Z Zagadnień Nauk Sadowych 1999; 77–94.
9. Guerguer M., Naamane S., Edfouf Z., Raccurt O., Bouaouine H. Chemical Degradation and Color Changes of Paint Protective Coatings Used in Solar Glass Mirrors, Coatings 2021; 11(4): 476. DOI: 10.3390/coatings11040476
10. Mohamed M.A., Jaafar J., A.F. Ismail, M.H.D. Othman, M.A. Rahman, Chapter 1 - Fourier Transform Infrared (FTIR) Spectroscopy, Editor(s): Nidal Hilal, Ahmad Fauzi Ismail, Takeshi Matsuura, Darren Oatley-Radcliffe, Membrane Characterization 2017; 3–29. DOI: 10.1016/B978-0-444-63776-5.00001-2.
11. Wenning M., Seiler H., Scherer S. Fourier-Transform Infrared Microspectroscopy, a Novel and Rapid Tool for Identification of Yeasts, Appl Environ Microbiol. 2002; 68(10): 4717–4721. DOI: 10.1128/AEM.68.10.4717-4721.2002.
12. Szczerbowska-Boruchowska M. Fourier Transform Infrared Microspectroscopy in Medical Diagnostics. Measurements, Automation, Control. PAK Publishing House 2007; 53(9): 444–447.
13. Milczarek J. Examination of paint traces using pyrolysis gas chromatography with mass spectrometry detection (Py-GC/MS) for forensic purposes. Doctoral thesis. Institute of Forensic Research named after Prof. Dr. Jan Sehn, Krakow, Poland 2009. [Link to publication: https://milczarek.eu/pl/publications/].
14. Fay F., Linossier I., Langlois V., Haras D., Vallee-Rehel K. SEM and EDX analysis: Two powerful techniques for the study of antifouling paints, Progress in Organic Coatings 2005; 54(3): 216–223. DOI:10.1016/j.porgcoat.2005.05.005.
15. Kaur N., Abi K.S., Verma P., Mahajan M. An elemental analysis of Indian automotive paint using SEM-EDS,Materials Today: Proceedings 2022; 48(5), 1748–1753. DOI: 10.1016/j.matpr.2021.10.046.
16. Żyłka W., Cieniek B., Skała P. Electron Magnetic Resonance Study of the Most Sensitive Metal Paint Components for Degradation. Advances in Science and Technology Research Journal 2023; 17: 101–109. DOI:10.12913/22998624/164724.
17. Osada K. The Ultraviolet Absorption Spectra of Glasses J. Phys. Soc. Jpn. 1951; 6: 191–192.
18. Boscaino R., Vella E. and Navarra G. Absorption edge in silica glass, Proceedings of 2005 IEEE/LEOS Workshop on Fibres and Optical Passive Components. Palermo, Italy 2005; 318–322. DOI: 10.1109/WFOPC.2005.1462147.