Advances in Science and Technology Research Journal

Advances in Science and Technology Research Journal, 2025, 19(5), 336–343
https://doi.org/10.12913/22998624/202138
ISSN 2299-8624, License CC-BY 4.0

Received: 2025.02.10
Accepted: 2025.03.15
Published: 2025.04.01

The effect of paint application pressure on the light reflectance coefficient

Wojciech Żyłka[1*], Piotr Potera[1]

[1] Institute of Materials Engineering, Faculty of Exact and Technical Sciences, University of Rzeszow, Pigonia 1, 35-310 Rzeszow, Poland

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

ABSTRACT

The article concerns experimental studies on the impact of the paint application method on the light reflectance coefficient in the wavelength range from 180 to 2500 nm, with particular emphasis on the analysis of reflectance in the infrared wavelength range, which affects surface heating. Additionally, studies were conducted on the effect of prior ultraviolet (UV) light exposure on the light reflectance coefficient. The results show that controlling the application pressure is a key parameter in optimizing the reflectance properties, particularly in the infrared range, which has a direct impact on surface temperature regulation. The findings are significant for improving coating durability and energy management efficiency. This research also highlights the potential for environmentally sustainable applications in the automotive industry and other sectors, by optimizing coating methods to reduce energy consumption and material degradation. Quantitative results from this study indicate that applying paint at pressures ranging from 1 to 5 bar leads to a change in the infrared reflectance coefficient (AR) of up to 24%, providing valuable insights into how application methods affect surface properties.

Keywords: paints, light reflectance

INTRODUCTION

Nowadays, a geometric structure of surface is quite important because of the following significant reasons: functional, exploitative and esthetic [1]. Recently, an intensive development of various metrology techniques for a surface layer [2–4] gives the opportunity to predict the functional and the exploitative attributes of the surface. One of the key applications of modern coating technologies is the optimization of the optical and thermal properties of surfaces. Optimized light reflectance coatings can reduce the heating of vehicles and extend the lifespan of outdoor equipment, leading, among other things, to a lower demand for air conditioning. This translates into reduced fuel consumption and carbon dioxide (CO_2) emissions, which is directly linked to a decrease in negative environmental impact. The reduced heating of vehicles also reduces energy consumption in other sectors, such as transportation, where vehicles with optimized coatings can have more efficient heat management systems. The development of durable paints and coatings that are less susceptible to degradation leads to a less frequent need for replacement, which reduces waste and the consumption of natural resources. Studies on the degradation of coatings using electron paramagnetic resonance (EPR) methods enable the identification and elimination of components that contribute to the faster wear of coatings [5, 6]. Furthermore, spectrophotometric studies of paints and coatings can assess the durability and quality of the coating, such as the impact of curing temperature on its light permeability [7–11]. The use of more durable paints and coatings also reduces the need for chemical agents and processes related to the repair and renewal of coatings, which has a positive environmental impact. The automotive industry is a key sector of the economy that significantly affects the environment. The introduction of innovative coating technologies that reduce vehicle heating and improve coating durability is in line with global trends towards more sustainable transportation. Research on the impact of the paint application method on surface heating enables the development of new application technologies that may be more environmentally friendly and efficient. Analyzing the impact of coatings on surface heating in real-world conditions allows for the direct translation of research results into practical applications in the automotive industry. This, in turn, supports the implementation of technologies aimed at reducing negative environmental impact. The results of the research may lead to the development of more sustainable automotive products that align with regional and global environmental policy goals. Research on paints with varying light reflectance requires advanced material analysis, their properties, and their impact on the surface temperature of automotive bodies. Understanding the mechanisms of light reflection, absorption, and emission by different materials is crucial for assessing the thermal effectiveness of paints.

Spectrophotometric studies

Light reflectance studies of coatings were conducted using a Cary 5000 spectrophotometer. This is a dual-beam spectrophotometer. The light beam, regulated by a slit, is directed onto a littrow monochromator (two diffraction gratings with a density of 1200 lines/mm in the ultraviolet-visible (UV-Vis) range). The light source in the spectrometer is a tungsten-halogen lamp with a quartz window (visible and infrared light) and a deuterium lamp (UV) (Fig. 1).

The spectral range for the deuterium lamp is 175 nm to 375 nm, while for the halogen lamp, it spans from 375 nm to 3300 nm. An R928 high-performance photocathode was employed as the UV-Vis detector. To enhance performance in the infrared region, reduce noise, and ensure better linearity compared to standard photomultipliers, a thermally controlled PbSmart photomultiplier detector utilizing lead sulfide technology was used [12, 13]. Additionally, an optical isolation system was implemented to achieve low noise levels and minimize environmental interference.

For the study of light reflection, a diffuse reflection attachment (DRA) (Fig. 2) was used, enabling the measurement of total reflection (both diffuse and specular components) in an appropriate configuration [14].

The measurement of the total reflectance coefficient was performed by placing the sample on the rear wall of the integrating sphere, ensuring the effective collection of a large portion of diffusely reflected radiation along with the inclusion of the specularly reflected radiation component (Fig. 3).

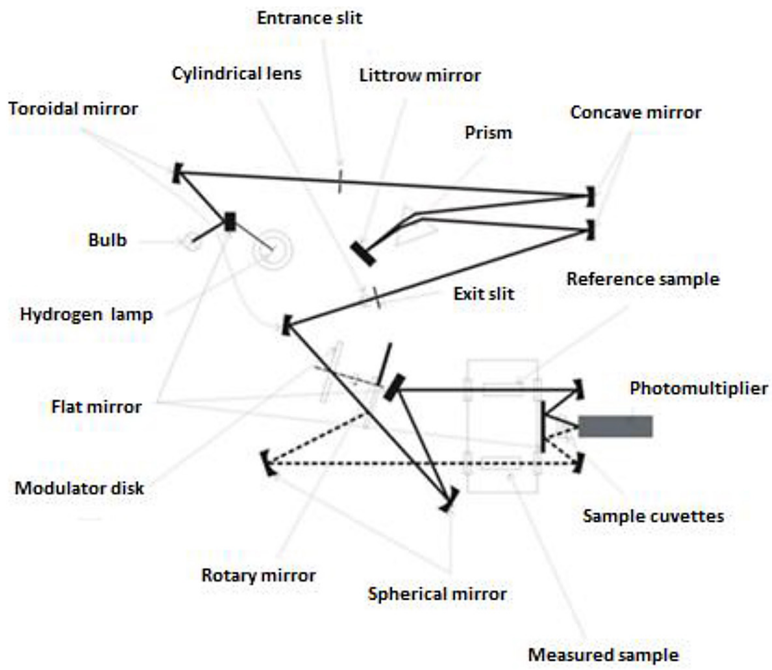

Figure 1. Beam path in the Cary 5000 spectrophotometer

Figure 2. Internal DRA, DRA-2500 (PMT/PbS version), internal version

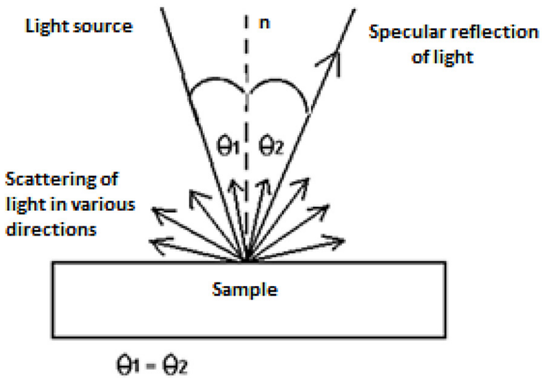

Figure 3. Two components of reflection: specular (directional) reflection and diffuse reflection. n denotes the normal to the surface, i.e., the line perpendicular to the sample surface, (θ_1 – angle of incidence, θ_2 – angle of reflection)

The DRA for the Cary 5000 consists of an integrating sphere with a diameter of 110 mm. The internal coating of the sphere is made of polytetrafluoroethylene (PTFE), which exhibits higher reflectance efficiency in the near infrared (NIR) range than traditional coatings, while maintaining UV-Vis efficiency. The sphere is easily installed using a locking mechanism in the measurement chamber of the spectrometer. The measurement of the total reflectance coefficient of the sample is typically performed with reference to a reference material (either a PTFE plate or Barium sulphate ($BaSO_4$)) or a standard reference material [12, 13]. The reference material is used to establish the so-called baseline. In our case, the Labsphere certified reflectance standard USRS-99-020 AS-01159-60 was used as the reference, which is commonly employed for baseline calibration [15, 16].

Preparation of samples for analysis

For the studies, aluminum plates with dimensions of 100 × 50 × 3 mm were selected, onto which a coating was applied (Fig. 4). These surfaces were properly prepared. To clean the samples from contaminants such as dust or grease, isopropyl alcohol (IPA) and a microfiber cloth were used. Each sample was gently wiped, taking care not to damage the surface. Then, the coating was cleaned of any remaining isopropyl alcohol by rinsing the samples with distilled water, after which they were thoroughly dried. After the cleaning stage, visual inspection of the samples was conducted to confirm the absence of defects that could significantly affect the application of the paint coating or the subsequent roughness and light reflectance measurements.

According to the manufacturer's recommendations, 50% hardener and 10% acrylic thinner were added to the acrylic paint. The goal was to coat small surfaces, with a total area of approximately 0.025 m². In a small container, 50 ml of paint was mixed with 25 ml of hardener and 7.5 ml of thinner.

A high-pressure (HP) spray gun from Airpress was used for painting. This spray gun has a gravity-fed reservoir that uses gravity to supply paint to the gun nozzle. The spraying viscosity is 18–21 seconds at 20 °C, with a 2.0 mm nozzle (Fig. 5), and the pressure ranges from 1 to 5 bar. The distance from the spray gun to the painted surface was 20 cm.

Figure 4. Aluminum plates onto which the paint coating was applied [17]

Figure 5. 2.0 mm nozzle [17]

The properly prepared plates were coated with paint at different application pressures. The first sample at 1 bar, the second at 2 bars, the third at 3 bars, the fourth at 4 bars, and the fifth at 5 bars. The thickness of the paint coatings was 50 µm. After applying the coatings, the samples were left to dry in a room with a temperature of 21.3 °C and a humidity of 48%.

The influence of paint application pressure on surface roughness

The roughness measurements were performed using the MarSurf XCR20 device. The roughness parameters of each painted sample and one unpainted sample, referred to as "Clean", were measured. In the analysis process, the standards specified in ISO 16610-21 were followed, which defines the metrological methods of Gaussian filters used for processing surface profiles. The obtained roughness parameter values are presented in Table 1, and a graphical representation of the effect of paint application pressure on selected roughness parameters is shown in Figure 6.

Analyzing the obtained roughness parameter values (Table 1, Fig. 6), it can be concluded that the paint application pressure affects the formation of surface roughness. The observed differences in the range from 0.330 µm to 0.835 µm for selected roughness parameters suggest that proper adjustment of the pressure can be used to achieve the desired coating smoothness. It is noteworthy that the values of some roughness parameters for the clean sample (Fig. 6) were comparable to those of the other painted samples, indicating that low roughness can be achieved with proper paint application pressure selection.

Study of the influence of paint application pressure on the surface light reflectance coefficient value

To measure the total reflectance coefficient of the paint coating surface, a spectrophotometer with a diffuse reflectance accessory (DRA) was used. The total reflectance coefficient was measured by placing the sample on the rear wall of the integrating sphere, ensuring the effective collection of a large portion of diffusely reflected radiation, along with the inclusion of the specularly

Table 1. The obtained surface roughness results for samples coated with paint at various application pressures [17]

Parameter	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Clean sample
Ra (µm)	0.835	0.741	0.330	0.371	0.808	0.834
Rq (µm)	1.044	0.960	0.515	0.510	0.980	1.167
Rz (µm)	4.988	3.530	3.283	2.829	3.533	7.563
Rmax (µm)	7.645	4.893	8.155	4.288	4.464	14.194
Rz1max (µm)	7.645	4.893	8.155	4.288	4.464	14.194
RzJ (µm)	1.768	1.443	1.562	1.359	0.923	4.294
Rt (µm)	8.699	4.974	8.155	4.871	4.464	14.194
Rp (µm)	3.039	2.255	2.333	1.881	1.984	2.194
Rpm (µm)	3.039	2.255	2.333	1.881	1.984	2.194
Rpmax (µm)	6.074	3.297	6.520	3.502	2.680	2.689
Rp (ASME) (µm)	6.074	3.297	6.520	3.502	2.680	2.689
Rv (µm)	1.949	1.275	0.950	0.948	1.549	5.369
Rvm (µm)	1.949	1.275	0.950	0.948	1.549	5.369
Rvmax (µm)	2.625	1.677	1.635	1.369	1.783	11.505
Rv (ASME) (µm)	2.625	1.677	1.635	1.369	1.783	11.505

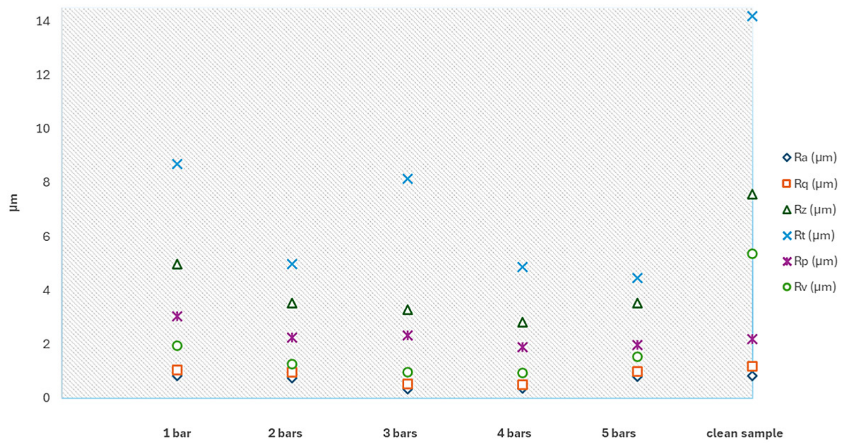

Figure 6. Effect of paint application pressure on selected roughness parameters

reflected radiation component. An analysis of the effect of paint application pressure on the light reflectance coefficient of the paint coatings was conducted, as this coefficient significantly depends on the application pressure (Fig. 7).

In the ultraviolet range, a decrease in the total reflectance coefficient with increasing wavelength up to around 350 nm can be observed (Fig. 7), after which a sharp increase in this coefficient is seen, reaching maximum values of about 84.5% at 530 nm, somewhat dependent on the spraying pressure. The reflectance coefficient in the visible range is almost independent of the spraying pressure (except for the 1 bar sample). In the infrared region, a decreasing trend of the reflectance coefficient with wavelength is observed. In this spectral range, the reflectance coefficient significantly depends on the lacquer spraying pressure. For a spraying pressure of 1 bar, the lowest reflectance (around 21% at 2460 nm) was obtained. Increasing the spraying pressure to 2 and 3 bars results in an increase in the reflectance coefficient to 38% and 46%, respectively. Further increases in spraying pressure (4 and 5 bars) cause a decrease in the reflectance coefficient, which then reaches values similar to those for 2 bars.

Analysis of the effect of UV radiation on the light reflectance coefficient

The surface tests of the painted coatings at different application pressures were repeated after one hour of irradiation of the samples using two ultraviolet (UVA) diodes, each with a wavelength of 460 nm and a power of 3 W. Some changes in the light reflectance coefficient were observed, as shown in Figure 8.

A particular effect of UVA radiation on the deterioration of light reflectance by about 6% *R* in the wavelength range from 410 nm to 1300 nm was

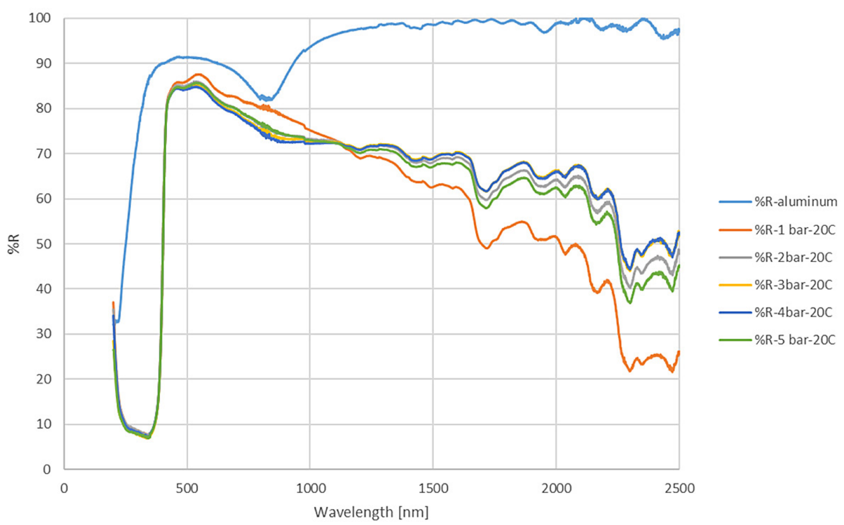

Figure 7. Reflectance of the paint coating at different application pressures

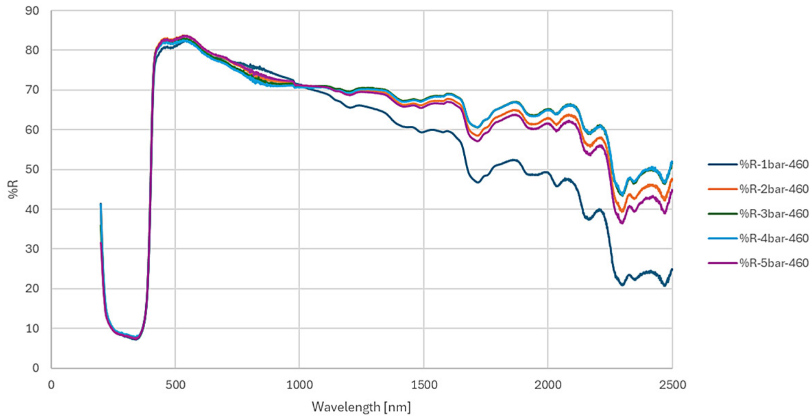

Figure 8. Reflectance of the paint coating at different application pressures after UVA exposure

observed for samples with coatings applied at 1 bar pressure (Fig. 9) and 4 bar pressure (Fig. 10).

Further studies were conducted by irradiating the samples with ultraviolet C (UVC) light from a 15W lamp with a wavelength of 253.7 nm, which allowed assessing the impact of this radiation range on the reflectance properties of the surface. A further decrease in light reflectance was observed on each of the analyzed samples, particularly in the wavelength range from 420 to 1500 nm (Fig. 11). It should be noted that UV light does not affect the reflectance of the coating in the UV and violet light range.

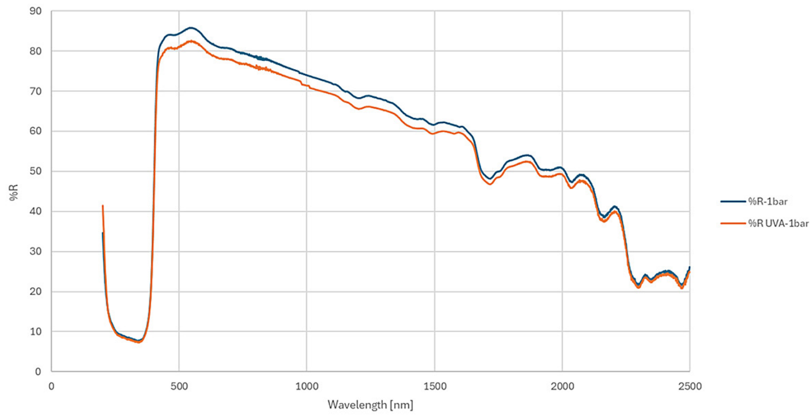

Figure 9. Comparison of light reflectance of the paint coating applied at 1 bar pressure before (blue line) and after UVA irradiation (orange line)

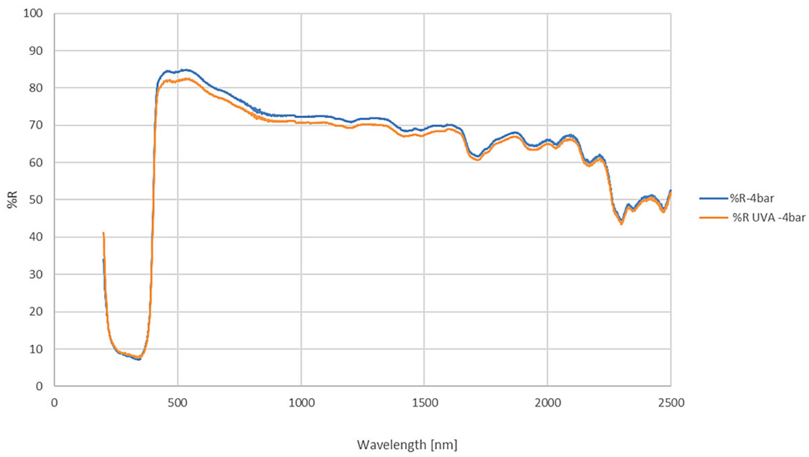

Figure 10. Comparison of light reflectance of the paint coating applied at 4 bar pressure before (blue line) and after UVA irradiation (orange line)

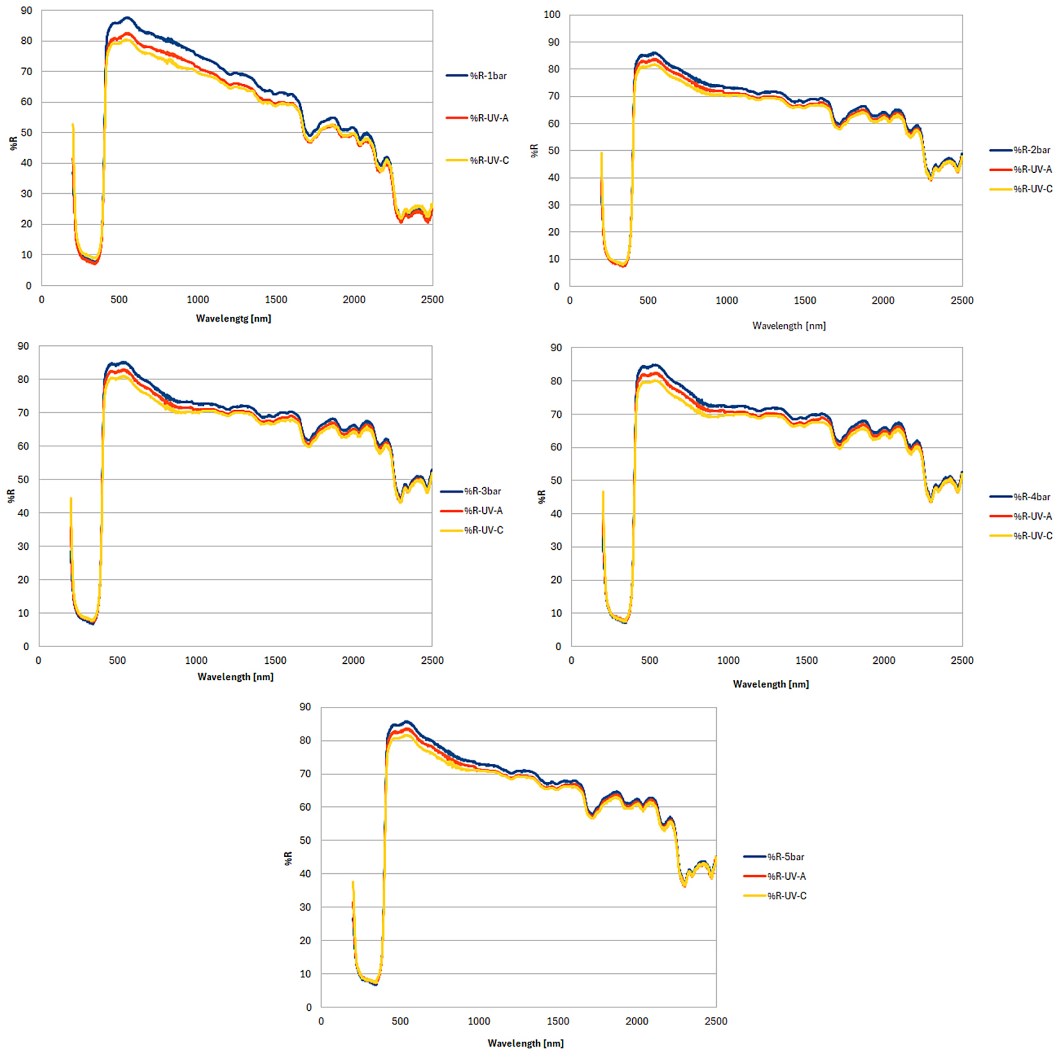

Figure 11. Reflectance of the paint coating after UVA and UVC irradiation for coatings applied at 1, 2, 3, 4, and 5 bar pressures

As a result of the experiment, it was observed that the light reflectance coefficient of the paint coating gradually decreased in all samples (1, 2, 3, 4, and 5 bar) during both UVA and UVC irradiation. After one hour of irradiation for each type of radiation (UVA and UVC), the decrease in reflectance was up to 6% in each sample.

The results of the experiment indicate that UV radiation negatively affects the light reflectance properties of the studied paint coating. Both UVA and UVC radiation led to a gradual decrease in the light reflectance coefficient.

CONCLUSIONS

The impact of paint application pressure on surface roughness and the light reflectance coefficient of paint coatings was investigated. Different paint application pressures were applied in the experiment, with measurements of roughness and light reflectance taken, followed by analysis of the results. It was found that paint application pressure has a significant effect on the surface structure, with roughness changes ranging from 0.330 µm to 0.835 µm, indicating the potential for precise adjustment of coating smoothness.

The light reflectance coefficient, particularly in the infrared range, also depends on application pressure. Increasing the pressure from 1 bar to 3 bars led to a 17% increase in reflectance, suggesting that controlling pressure can optimize reflectance properties, especially in heat management, which is crucial for automotive and aerospace industries.

Additionally, exposure to UV radiation negatively affects the durability of paint reflectance. After 1 hour of UVA exposure, reflectance dropped by approximately 6% across all samples.

Coatings applied at lower pressures (1 bar) showed greater susceptibility to UV degradation, highlighting the need for UV-resistant coatings in applications requiring long-term durability.

From an environmental perspective, the study's results indicate that controlling paint application pressure can contribute to reduced energy consumption, lower CO_2 emissions, and increased durability of paint coatings, supporting sustainability through waste reduction and minimizing the need for frequent repairs.

REFERENCES

1. Macek W., Sampath D., Pejkowski Ł., Żak K. A brief note on monotonic and fatigue fracture events investigation of thin-walled tubular austenitic steel specimens via fracture surface topography analysis (FRASTA), Engineering Failure Analysis, 2022; 134: 106048. DOI: 10.1016/j.engfailanal.2022.106048.
2. Kłonica M. Application of the ozonation process for shaping the energy properties of the surface layer of polymer construction materials. Journal of Ecological Engineering 2022; 23(2): 212–219. DOI: 10.12911/22998993/145265.
3. Fic S., Kłonica M., Szewczak A. Adhesive properties of low molecular weight polymer modified with nanosilica and disintegrated ultrasonically for application in waterproofing ceramics. Polimery/Polymers, January 2015; 60(11–12): 730–7341. DOI: 10.14314/polimery.2015.730.
4. Kłonica M., Bielawski R., Żokowski M. Comparative tests of shear strength of adhesive lap joints after thermal shocks. Advances in Science and Technology Research Journal.- 2021; 15(4): 364–375. DOI: 10.12913/22998624/143270.
5. Żyłka, W.M., 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(3): 101–109. DOI: 10.12913/22998624/164724.
6. EPR in Material Science and Physics. Paint properties. https://www.bruker.com/pl [accessed on January 8, 2025].
7. Żyłka, W.M., Potera, P. Testing of the light transmittance of industrial varnishes. Advances in Science and Technology Research Journal 2024; 18(3): 14–20. DOI: 10.12913/22998624/185463.
8. Colombini M.P., Modugno F., Giannarelli S., Fuoco R., Matteini M. GC-MS characterization of paint varnishes, Microchemical Journal 2000; 67(1–3): 385–396, DOI: 10.1016/S0026-265X(00)00098-9.
9. Kuzmendo P.J., Zeibel J.G., Huynh Q. Hemispherical total reflectance from 2 to 20 micron wavelength for vacuum compatible IR black coatings, Advances in Optical and Mechanical Technologies for Telescopes and Instrumentation III. Austin, TX, United States June 10, 2018. Spectrophotometers. DOI: 10.1117/12.2313014.
10. Huynh M. Analyzing Reflectance Data for Various Black Paints and Coatings. https://www.sto.nato.int. MP-SET-277-12 [accessed on January 8, 2025].
11. Hubicki Z. Science and Industry: Spectroscopic Methods in Practice - New Challenges and Opportunities. Maria Curie-Skłodowska University in Lublin, Faculty of Chemistry. Lublin 2022.
12. Diffuse reflectance accessory (Internal). Varian Cary WinUV Help.
13. Diffuse reflectance accesories (DRAs) for the Cary 4000, 5000, 6000i, or 7000 UV-Vis-NIR.
14. Yang P.W., Mantsch H.H., and Baudais F. A critical evaluation of three types of diffuse reflectance infrared accessories, Appl. Spectrosc 1986; 40: 974–978.
15. Jacot R., More R., Michalsky R., Steinfeld A., Patzke G.R. Trends in the phase stability and thermochemical oxygen exchange of ceria doped with potentially tetravalent metals, J. Mater. Chem 2017 A; 5: 19901–19913.
16. Wesołowski M., Potera P. Determination of bolometric albedo based on spectroscopic measurements for selected dust analogues and its impact on the change of cometary brightness during its outburst, Astronomy & Astrophysics 2024; 686: A248.
17. Jakubowska U. Analysis of the impact of paint application pressure on the surface roughness of coating layers. Engineering thesis. University of Rzeszów. Rzeszów 2024.