

Ўзбекистон

# **K**ompozitsion **M**ateriallar

Ilmiy-texnikaviy va amaliy jurnali



Ўзбекский научно-технический и производственный журнал  
**Композиционные материалы**

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### EFFECT OF ALUMINUM COATING THICKNESS ON THE PERFORMANCE CHARACTERISTICS OF REFLECTORS

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**Abstract.** The present study investigates the effect of aluminum coating thickness on the key performance characteristics of reflectors, with particular emphasis on optical efficiency, resistance to atmospheric exposure, and operational durability. Aluminum coatings were deposited using a vacuum deposition technique, producing reflective layers with varying thicknesses. A comparative analysis of the samples was carried out to evaluate changes in reflectance, surface uniformity, and corrosion resistance as a function of coating thickness. The results demonstrate that insufficient aluminum layer thickness leads to reduced reflectance and lower environmental stability due to incomplete surface coverage, whereas excessively thick coatings may cause the development of internal stresses and a deterioration of adhesion properties. An optimal range of aluminum coating thickness was identified, providing a balanced combination of high reflectance, enhanced resistance to atmospheric degradation, and long-term durability under different operating conditions. The findings of this study offer practical guidance for optimizing aluminum coating parameters in the design and manufacturing of optical, lighting, and heat-reflective systems.

**Keywords:** aluminum coating, reflector, reflectance, corrosion resistance, layer thickness, vacuum deposition.

**Introduction.** Reflectors are widely employed across various fields of engineering—from lighting devices and solar collectors to antennas and scientific measuring systems. One of the key parameters determining reflector efficiency is its reflectance, which is directly dependent on the coating material and the deposition technique. Aluminum is the most commonly used material for reflective coatings, owing to its high reflectance over a broad range of wavelengths.

Aluminum reflective coatings on automotive reflector surfaces are typically deposited via thermal evaporation under high-vacuum conditions, a process that enables precise control over film thickness and ensures high purity and uniformity of the resulting layer (Figure 1).

However, both the reflectance of the aluminum layer and its resistance to external influences are strongly influenced by coating thickness.

Excessively thin layers may exhibit poor resistance to mechanical and chemical impacts, whereas an excessive increase in thickness can degrade optical properties due to internal scattering and defect formation. The present study examines the influence of aluminum coating thickness on the performance characteristics of reflectors, including reflectance, corrosion resistance, and mechanical strength.

The determination of aluminum coating thickness on automotive headlight reflectors requires the application of both non-destructive and, where necessary, destructive analytical techniques. Among the non-destructive methods, eddy-current and inductive thickness gauges are frequently employed due to their ability to provide rapid, point-specific measurements without impairing the integrity of the substrate.



Figure 1. Vacuum installation for obtaining aluminum coatings

Optical techniques, including reflectometry and interferometry, may also be applied to achieve high-resolution surface characterization. For applications where enhanced precision or in-depth material characterization is required, destructive or semi-destructive methods such as cross-sectional microscopy, scanning electron microscopy (SEM), or X-ray fluorescence (XRF) analysis are utilized. The choice of method is typically guided by several factors, including the required accuracy of measurement, the acceptable degree of reflector alteration, and the physical and chemical properties of the deposited aluminum layer. This methodological flexibility ensures that the most suitable technique can be selected according to the balance between analytical precision and preservation of the component.

**Materials and Methods. Samples and Coating Deposition Technique.** For the study, aluminum coatings of varying thicknesses (ranging from 50 to 500 nm) were prepared using vacuum deposition onto glass and polymer substrates [1–3]. High-purity aluminum (99.99%) was employed as the source material. The coating thickness was monitored during deposition using a quartz crystal microbalance sensor and further verified by atomic force microscopy (AFM) and profilometry.

**Methods of testing.** The performance properties were studied in the following directions:

- **Reflectance** - measured using a spectrophotometer in the range of 300–1100 nm.
- **Corrosion resistance** - evaluated after accelerated climatic tests in a salt spray chamber and under cyclic humidity conditions.
- **Coating adhesion** - determined by the tape test method.
- **Surface morphology** - examined using scanning electron microscopy (SEM).

## Results and Discussion.

### 1. Dependence of reflectance on thickness.

The thickness of aluminum coatings is a key determinant of optical reflectance and reflector performance in automotive lighting systems. While very thin films (<50 nm) fail to deliver sufficient reflectance or durability, coatings in the range of 100–150 nm achieve optimal optical performance while balancing production cost, mechanical integrity, and long-term reliability. As vehicle lighting technology continues to evolve, precise control of aluminum coating thickness-along with protective overcoating techniques-remains critical for ensuring efficient, safe, and aesthetically pleasing reflector designs.

Automobile reflectors serve a fundamental role in headlight and taillight systems by redirecting light from the source to achieve uniform and efficient illumination. The optical efficiency of these systems depends heavily on the reflectance of the inner coating, typically made of vapor-deposited aluminum. Since reflectance is highly sensitive to the thickness and microstructure of the metallic layer, understanding this dependency is crucial for optimizing reflector design and manufacturing processes.

Aluminum, as a metallic reflector, exhibits high reflectance in the visible range (400–700 nm), often reaching values of 90–93% under ideal conditions. However, the reflectance of thin aluminum films varies significantly with thickness, especially in the nanometer scale:

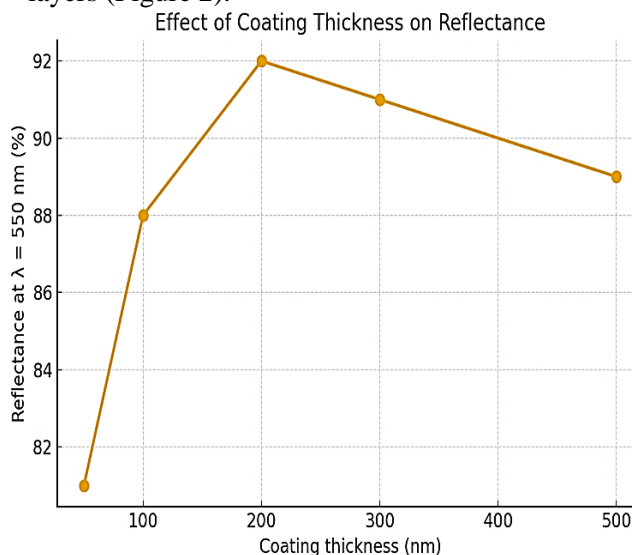
**Sub-critical thickness (< 30 nm):** At very low thicknesses, the aluminum film is often discontinuous or partially transparent, leading to low optical reflectance and increased absorption. Incomplete surface coverage can cause light leakage and scattering, which severely degrades reflector performance.

**Growth and transition region (30–100 nm):**

As the film thickens, continuity improves and reflectance increases significantly. In this range, the film begins to behave like a bulk material, and specular reflectance dominates over diffuse scattering.

**Saturation regime (>100 nm):** Beyond approximately 100–150 nm, the reflectance plateaus, reaching values comparable to bulk aluminum. Further increases in thickness offer minimal optical improvement, although they may enhance mechanical durability.

Analysis of the spectral characteristics revealed that the reflectance increases with the thickness of the aluminum layer up to a certain threshold (~200 nm). With further thickening, saturation is observed and, in some cases, a slight decrease in reflection in the ultraviolet range (300–400 nm), which can be attributed to interference effects and the formation of microdefects in thicker layers (Figure 2).



**Figure 2. Effect of coating thickness on reflection efficiency**

**2. Corrosion resistance**

Samples with a thickness below 100 nm exhibited poor resistance to salt spray: after only 48 hours, oxide inclusions and surface tarnishing were observed. In contrast, coatings with a thickness of 200–300 nm retained their gloss and reflective properties for 96 hours or more. This behavior can be attributed to the barrier effect of thicker layers, which hinder the penetration of moisture and aggressive ions to the substrate [4-6].

**3. Adhesion properties**

Maximum adhesion was observed for coatings with a thickness of 100–200 nm. At smaller thicknesses, the coating was easily peeled off, especially on polymer substrates. At thicknesses above 300 nm, cracking of the coating during bending was likely, particularly in cases of insufficient surface preparation of the substrate [7-11].

**4. Surface morphology**

SEM analysis revealed that at the optimal thickness (100–200 nm), the coating surface was the most homogeneous and smooth. With increasing thickness above 300 nm, signs of granulation and microcrack formation were detected, which can potentially reduce the service life of the reflector.

**Conclusion.** The conducted studies confirmed the significant influence of aluminum coating thickness on the performance characteristics of the reflector. The optimal thickness range to ensure high reflectance, corrosion resistance, and adhesion was found to be 150–250 nm. Thinner coatings lack sufficient durability against external factors, whereas excessively thick coatings are prone to microdefects and reduced adhesion.

The obtained results can be applied in the design of lighting, optical, and thermal devices where high reflectance and long-term durability of the reflector are of critical importance.

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## СОДЕРЖАНИЕ

## 1. Химия и физикохимия композиционных материалов и нанокomпозитов

- Негматов С.С., Абед Н.С., Негматова К.С., Туляганова В.С., Негматов Ж.Н., Касимов Ш.Б., Бозорбоев Ш.А., Муродов И.И., Эргашев Н.Э., Абдукаххоров А.А., Саидкулов С.А.** О механизме физико-химических взаимодействий компонентов композиционных полимерных материалов, наполненных неорганическими и органическими ингредиентами ..... 3
- Абед Ф.Ж., Иногамов С.Е., Туреева Г.А.** Разработка и валидация методов анализа экстракта Алоэ и метилурацила в комбинированных фитоплёнках ..... 9
- Негматов С.С., Бабаханова М.А., Касимова М.Н., Раупова Д.Н., Шамсиевна С.С.** Исследование влияния состава на свойства композиционных лакокрасочных материалов на основе местного сырья, применяемых в различных отраслях промышленности ..... 13
- Сафаева Д.Р., Шукруллаева М.С., Тиллаев Т.У., Шин И.Г.** Взаимосвязь структуры и энергетического состояния запечатываемых полимерных пленок с напряжением коронного разряда при их активации .... 16
- Негматов С.С., Хурсанов А.Х., Негматов Ж.Н., Негматова К.С., Абед Н.С., Холмурадова З.К., Икрамова М.Э., Эрнийёзов Н.Б.** Исследование состава и технологических режимов флотационного обогащения медно-молибденовых руд месторождения «Кальмакыр» с применением флотореагента-вспенивателя КХФ-ВС..... 18
- Жумаева А.А.** Модификацияланган поливинилхлориднинг юмшаш ҳароратларини ўрганиш ..... 21
- Khusanova M.F., Djalilov A.T., Beknazarov X.S.** Synthesis and physicochemical characterization of highly absorbent oleogels ..... 24
- Эшдавлатова Г.Э., Камолов Л.С., Бобилова Ч.Х.** Исследование эффективности пенообразования на основе блок-сополимеров в растворах диэтанолamina ..... 27
- Radjabov O.I., Yariev O.O., Azimova L.B., Djurabaev Dj.T., Filatova A.V., Turaev A.S.** Na-KMS va I tip kollagenning o‘zaro ta’sirini molekulyar doking usulida ilmiy asoslash ..... 30
- Айтмуратова А.Е., Сидрасулиева Г.Б., Каттаев Н.Т., Акбаров Х.И., Дадаходжаев А.Т.** Синтез нанодисперсного NiO из отработанного промышленного катализатора ТО-2 и исследование его структурных и адсорбционных свойств ..... 34

## 2. Физико-механика и трибология композиционных материалов

- Abed N., Negmatova K., Tulyaganova V., Tukhtasheva M., Shamsiyeva S., Kosimov Sh.** Investigation of the influence of the nature and type of fillers on the antifriction-wear-resistant properties of composite polymer coatings ..... 39
- Алланазаров А.А.** Оқ чўянларни кесувчи асбоб тифининг ейилишга бардошлигини назарий тадқиқи ..... 42
- Berdiyev D.M., Liang Z., Abdullayev A.X., Ibroximova M.M.** Nikel asosli olovbardosh qotishmalar xossalariга metallmas qo‘shimchalarning ta’siri ..... 44
- Абдуллаев Ф.К., Йулдошев О.Ч.** Экспериментальное исследование жидкотекучести чугуновых сплавов. 47
- Алланазаров А.А., Ахмедов А.Х., Шакиров Ш.М., Хусанов У.С.** Оқ чўянга механик кесиб ишлов бериш жараёнини назарий тадқиқ этиш ..... 50
- Saidakhmedova G.R., Inoyatkhodjaev J.Sh., Saydakhmedov R.Kh., Parpiev M.M.** Effect of aluminum coating thickness on the performance characteristics of reflectors ..... 54
- To‘rayev A.N., Murodqosimov R.X., Axmedova M.E., Solijonova Sh.X., Xolmatov E.M., Rajabova M.A.** Nikel qo‘shimchasining alyuminiy qotishmalarining yeyilishbardoshligiga ta’sirini o‘rganish ..... 57
- Kodirov O., Safarov T., Beknazarov Kh.** Study kinetic results of the inhibitors synthesis of corrosion inhibitor based on P-phenylenediamine, formalin and alanine ..... 59

## 3. Разработка и технология получения композиционных материалов

- Абед Н.С.** Разработка метода формирования электропроводящих композитов с сегрегированной структурой, содержащих наноразмерный углеродный наполнитель ..... 64