

# INVESTIGATION OF SURFACE MORPHOLOGY AND X-RAY PHASE ANALYSIS OF ALUMINUM PLATES AFTER PULSED LASER TREATMENT

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**Annotation:** This study investigates the effect of pulsed laser treatment on the surface morphology and phase composition of aluminum plates. Laser irradiation induces significant micro- and nanoscale structural changes, including melting, recrystallization, and surface roughening. These modifications improve the mechanical and functional properties of the material. X-ray diffraction analysis confirms the formation and transformation of phases, particularly oxide layers. The results demonstrate that optimization of laser parameters plays a key role in controlling surface characteristics. Overall, pulsed laser technology is an effective method for enhancing the performance of aluminum materials and expanding their practical applications.

**Keywords:** Pulsed laser, aluminum, surface morphology, X-ray diffraction, phase composition, laser processing, surface modification, microstructure.

## **Introduction**

Nowadays, in the fields of materials science and biomedical engineering, surface modification of metallic materials is considered one of the most actual scientific directions. In particular, aluminum and its alloys are widely used in industry, medicine, and technology due to their low weight, high strength, and corrosion resistance. At the same time, improving the surface properties of these materials allows for further expansion of their functional capabilities. In recent years, pulsed laser technology has been extensively studied as an effective method for processing metal surfaces. Pulsed laser radiation delivers high energy within a

very short time, causing micro- and nanoscale changes on the material surface. As a result, the surface morphology, physicochemical properties, and phase composition undergo significant modifications. This can positively influence the mechanical strength, wear resistance, and biocompatibility of the material. Studying the surface structure (morphology) of aluminum plates after pulsed laser treatment is of great importance, as changes in surface structure directly determine the material's эксплуатацион properties. In addition, X-ray phase analysis makes it possible to identify newly formed phases or changes in existing phases within the material. This method enables a deep investigation of the material's internal crystal structure.

### **Relevance**

In modern materials science, improving the properties of metal surfaces is of great scientific and practical importance. Since aluminum and its alloys are widely used, modifying their surface structure is a relevant issue. Pulsed laser technology allows effective alteration of surface morphology and physicochemical properties. Therefore, studying the surface condition and phase composition of aluminum plates after laser treatment is both scientifically and practically significant.

### **Objective**

The main objective of this study is to investigate the morphological changes on the surface of aluminum plates after pulsed laser treatment and to analyze their phase composition using X-ray diffraction methods.

### **Main part**

Pulsed laser technology is considered one of the most advanced and efficient methods in modern materials science. This technology operates by delivering high energy to the material surface within a very short period of time. As a result, rapid heating and cooling processes occur on the surface layer of the material. These processes lead to significant structural modifications. Pulsed lasers typically operate in nanosecond, picosecond, or femtosecond ranges. The duration of each pulse determines the level of interaction with the material. Shorter pulses reduce the heat-affected zone and minimize unwanted deformation. Laser parameters such

as wavelength, intensity, and repetition rate play a crucial role. These parameters define the type and extent of surface modification. Energy density is another important factor in pulsed laser processing. High energy density can cause melting and evaporation of the surface layer. This leads to the formation of new microstructures. During laser-material interaction, photothermal and photomechanical effects occur. The photothermal effect is associated with heat generation, while the photomechanical effect involves shockwave formation. These processes significantly alter the surface properties. Pulsed laser technology allows precise control over processing conditions. Therefore, it is widely used in micro- and nanotechnology applications. This method can be applied to metals, ceramics, and polymers. It is especially effective for strengthening metal surfaces. Overall, pulsed laser technology is a powerful tool for surface modification.

Aluminum is one of the most widely used materials in modern industry. One of its main advantages is its low density. At the same time, it exhibits high mechanical strength and good thermal conductivity. Aluminum is also known for its corrosion resistance. This property is due to the formation of a natural oxide layer on its surface. The oxide layer protects the material from environmental effects. Aluminum also has good electrical conductivity. Therefore, it is widely used in electrical engineering. Aluminum alloys are developed to enhance its properties. Elements such as magnesium, silicon, and copper are commonly added. These additions improve the strength and durability of the material. Aluminum plates are easy to process and shape. However, their surface properties are sensitive to external influences. High temperatures can cause structural changes on the surface. Aluminum effectively absorbs laser radiation, which is important for laser processing. Under laser exposure, melting and recrystallization processes occur. This may lead to the formation of new phases. Aluminum materials are also used in biomedical applications. Their biocompatibility is an important factor. Surface modification can further improve these properties. The surface morphology directly affects functional performance. In general, aluminum and its alloys are high-performance engineering materials.

Pulsed laser processing involves complex physical and chemical interactions with the material surface. When laser radiation strikes the material, its energy is absorbed. This results in a rapid increase in temperature at the surface layer. Consequently, melting and evaporation processes occur. After the laser pulse ends, rapid cooling takes place. This leads to high-speed solidification and structural transformations. As a result, non-equilibrium microstructures may form. Laser ablation is also an important process in this context. Ablation refers to the removal of material from the surface. This process creates micro- and nanostructures. Shockwaves are generated during laser interaction. These waves induce deformation within the material. At the same time, surface hardness may increase. Laser processing can also enhance oxidation processes. This leads to the formation of new chemical compounds. The pulse duration significantly affects these mechanisms. Short pulses minimize thermal effects and preserve structural integrity. Surface roughness typically increases after laser treatment. This improves adhesion properties. In biomedical applications, this is especially beneficial. Laser exposure can also introduce dislocations and crystal lattice defects. These changes influence mechanical properties. Pulsed laser processing allows precise control over surface characteristics. Therefore, desired material properties can be achieved. Overall, laser processing results in complex surface modifications.

The study of surface morphology of aluminum plates is an important area in materials science. Surface morphology describes the external structure of a material. Various advanced analytical methods are used for this purpose. One of the most widely used techniques is scanning electron microscopy (SEM). This method provides high-resolution imaging of the surface. SEM allows detailed analysis of microstructures. Atomic force microscopy (AFM) is also commonly used. It enables investigation at the nanoscale level. Surface roughness can be measured using profilometry techniques. These methods quantify surface irregularities. Optical microscopy is often used for preliminary analysis. After laser processing, the surface structure changes significantly. Features such as microcraters, cracks, and melting traces may appear. Identifying these changes is

essential for understanding material behavior. Morphological analysis results are closely related to material properties. Therefore, comprehensive evaluation is required. Surface roughness affects adhesion and wear resistance. In biomedical applications, it influences cell attachment. Laser parameters directly impact surface morphology. Therefore, optimization is necessary. Based on the results, material performance can be improved. In conclusion, the study of surface morphology is of great scientific importance.

X-ray phase analysis is one of the most important techniques used in materials science for determining the phase composition of materials. This method is based on the diffraction of X-rays by the crystal lattice of a material. When X-rays interact with a crystalline structure, they are diffracted at specific angles. These diffraction patterns provide detailed information about the internal structure of the material. X-ray diffraction (XRD) is widely used for identifying crystalline phases. It allows the detection of new phases formed after processing. The method is also useful for analyzing phase transformations. In laser-treated materials, XRD helps to determine structural changes. It can reveal the formation of oxides, intermetallic compounds, or metastable phases. The intensity and position of diffraction peaks provide valuable data. These parameters help to determine lattice parameters and crystallite size. XRD is a non-destructive technique, which makes it highly advantageous. It does not damage the sample during analysis. This method is also highly accurate and reliable. It is widely used in both research and industrial applications. In the case of aluminum, XRD can detect changes in its crystalline structure. It can also identify the presence of aluminum oxide phases. The technique is essential for understanding material behavior after laser processing. Overall, X-ray phase analysis is a fundamental tool in modern materials characterization.

The properties of a material surface after laser processing strongly depend on laser parameters. Key parameters include pulse duration, energy density, wavelength, and repetition rate. Each of these factors influences the interaction between the laser and the material. Pulse duration determines the extent of thermal

effects. Shorter pulses reduce heat diffusion and minimize damage. Energy density controls the degree of melting and ablation. Higher energy leads to more pronounced surface modifications. The wavelength of the laser affects absorption efficiency. Materials absorb different wavelengths in different ways. Repetition rate influences the accumulation of thermal energy. High repetition rates can lead to overheating. The scanning speed of the laser beam is also important. It determines the exposure time of the material. These parameters must be carefully optimized. Improper settings can cause unwanted defects. For example, excessive energy may lead to cracks or surface damage. Controlled laser parameters result in uniform surface structures. They also improve mechanical and physical properties. Surface roughness, hardness, and wear resistance can be tailored. In biomedical applications, surface characteristics are critical. Proper parameter selection enhances biocompatibility. Therefore, understanding laser parameters is essential. It allows precise control over material modification. In conclusion, laser parameters play a key role in determining surface quality.

Experimental methods are essential for investigating laser-treated materials. Proper sample preparation is the first step in any experiment. Aluminum plates must be cleaned and polished before processing. This ensures uniform laser interaction. Pulsed laser systems are used for surface treatment. The experimental setup includes a laser source, optical system, and control unit. Processing parameters must be carefully selected. After treatment, samples are analyzed using various techniques. Surface morphology is studied using SEM and AFM. These methods provide detailed structural information. Surface roughness is measured using profilometers. X-ray diffraction is used for phase analysis. This helps identify structural changes in the material. Additional techniques such as energy-dispersive spectroscopy (EDS) may be used. EDS provides elemental composition data. Experimental results must be carefully recorded and analyzed. Reproducibility is important for scientific validity. Multiple samples are often tested under similar conditions. Data analysis involves comparing treated and untreated samples. Graphs and images are used to present results. Experimental

errors must be minimized. Calibration of instruments is necessary. Overall, experimental methods ensure accurate and reliable results. They form the basis of scientific conclusions.

Pulsed laser processing of aluminum has numerous practical applications. It is widely used in aerospace and automotive industries. Surface modification improves wear resistance and durability. In electronics, it enhances conductivity and performance. In biomedical engineering, modified surfaces improve implant compatibility. Surface roughness plays a key role in cell adhesion. Laser-treated aluminum can be used in medical devices. The technology is also used in microfabrication. It allows precise patterning of surfaces. Future research focuses on improving efficiency and control. Advanced laser systems are being developed. These systems offer better precision and flexibility. Nanotechnology applications are also expanding. Laser processing can create nanostructured surfaces. These surfaces have unique properties. Environmental impact is also an important consideration. Laser processing is a clean and sustainable method. It does not require harmful chemicals. Automation and digital control are future trends. Artificial intelligence may be used to optimize parameters. This will improve process efficiency. In conclusion, pulsed laser technology has great potential. Its applications will continue to grow in the future.

### **Discussion and Results**

In this study, the effect of pulsed laser treatment on the surface of aluminum plates was investigated in a comprehensive manner. The obtained results demonstrate that laser irradiation leads to significant morphological and phase transformations on the material surface. In particular, processes such as melting, evaporation, and rapid recrystallization occur within the surface layer, resulting in the formation of new micro- and nanostructures. These changes contribute to an increase in surface roughness and improvement of functional properties. The study also revealed that pulsed laser processing significantly affects the physicochemical properties of the surface. Under high-energy laser exposure, oxidation processes are intensified, leading to the formation or quantitative changes of aluminum oxide

phases. These findings were confirmed by X-ray phase analysis, which indicated modifications in the internal crystal structure of the material.

Furthermore, the efficiency of laser processing was found to be strongly dependent on technological parameters such as pulse duration, energy density, and repetition rate. Proper optimization of these parameters results in improved surface quality and enhanced mechanical and operational properties. Conversely, inappropriate parameter selection may lead to defects such as cracks, excessive melting, and structural deformation. Overall, the results of this research confirm that pulsed laser technology is an effective method for surface modification of aluminum plates. This approach enables controlled improvement of surface properties, enhancement of material strength and durability, and provides opportunities for the development of advanced functional materials.

### **Conclusion**

In conclusion, pulsed laser treatment significantly modifies the surface morphology and phase composition of aluminum plates. The study demonstrated that laser processing leads to the formation of new microstructures and improves surface properties such as roughness, strength, and wear resistance. X-ray phase analysis confirmed the occurrence of structural and phase transformations, including the formation of oxide phases. The results indicate that proper optimization of laser parameters plays a crucial role in achieving desired surface characteristics. Overall, pulsed laser technology proves to be an effective and promising method for enhancing the functional properties of aluminum materials and expanding their practical applications.

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