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Particle Generation from Aluminum Alloy Surfaces Irradiated by 355nm Pulsed Laser and Multi-shots Laser Pretreatment Method at Low Fluences

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Abstract. The studies focus on particle generation from aluminium alloy surfaces irradiated by a Q switched Nd:YAG laser at 355 nm wavelength at low fluencies. The particles number increase with laser fluence but reduces with pulse number. The average initial threshold laser fluence for particles generation is 26.64 mJ/cm2. Larger particle with a diameter more than 5μm are found for fluencies above 76.54 mJ/cm2. After 40 pulsed laser shots at 72 mJ/cm2, it can effectively reduce the generation of metal particles. Our results demonstrated that 7075 aluminum alloy has the best laser resistance and the method of multi-shots laser pretreatment can reduced the generated particles by 76.92%. The SEM results shows that laser pretreatment process lead the passivation effct which smoothed the microstructure on the initial surface. The XPS results shows that zinc aluminate was generated during laser pretreatment process which has good thermodynamic properties. This study has important value for reducing metal particle contamination due to laser irradiation on metal surface in high power laser facilities and improving the service life of optical components.

1. Introduction

Aluminum alloy (AA) have been widely used in high power laser facilities as optical transmission vacuum pipes, optical component holders or diaphragms[1]. Unfortunately, if the problems of scattering light or ghost images are improperly handled in the pratical working of high power laser facilities, the scattering laser will inevitably beam on the aluminum alloy surface[2-3]. Then the metal particles sputter out from the surface and the detached particles may adhere to the optical component surface. This contaminants strongly absorb laser energy to cause optical surface damage[4-5]. This damage on optical components is fatal to high power laser facilities[6-7]. The study of metal particle generation has great research significance and application value for the long-term, stable and efficient operation of laser facilities.

The mechanism of laser interaction with metals has attracted growing interest in recent years. Most studies on the laser surface treatment of metals employed different kinds of lasers and the laser energy

is usually limited to high energies to improve specific performance[8-9]. Wojciech Pakieła, Tomasz Tanski, Mirosława Pawlyta, et al had reported the structure and mechanical properties of AlMg5Si2Mn alloy after surface alloying using fiber laser[10]. Excimer laser surface treatment of aluminum alloy was reported by T.M. Yue, L.J. Yan, C.P. Chan, et al about the improvement of AA7075 corrosion resistance[11]. Our preliminarily studies on pulsed laser interaction with AA6061 at low fluences have shown that the particle generation behavior of the aluminum alloys was very different from irradiated at high fluences.
In this paper, we report the result of particle generation from aluminum alloy surfaces irradiated by pulsed laser at low fluences to simulate the scattering laser in high power laser facilities. In order to reduce the number of generated particles from aluminum alloy surface, a multi-shots laser pretreatment method was proposed.

2. Experimental
The experimental samples were prepared using AA5083/6061/7075 specimens, measuring 100mm*100mm*5mm. When preparing the sample required for the experiment, the specimens were cleaned in absolute ethyl alcohol for 5 minutes using an ultrasonic cleaner. After the alcohol was fully volatized, the specimens were obtained.

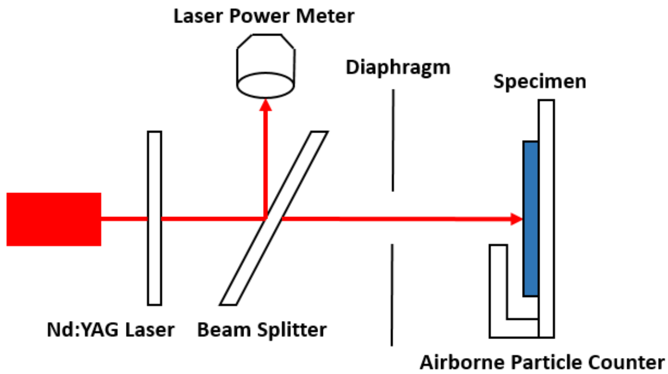

Figure 1. Schematic diagrams of experimental setups.

Figure 1 shows the schematic diagrams of experimental setups for scattering laser induced metal particle contamination experiment on aluminum alloy surface in the atmosphere. A Q switched Nd:YAG pulsed laser was operated at 355nm wavelength. The laser energy per pulse and pulse duration were 5 mJ ~340 mJ and 10 ns, respectively. The spot area was 75 mm2 (ellipse, the long and short axis was 6.3x3.8 mm @1/e2) and the laser fluence used in the experiment is calculated as 5.74 mJ/cm2~454.20 mJ/cm2 to simulate the scattering laser in high power laser facilities. Depending on the purpose of the experiments, an airborne particle counter (flow rate of 40 L/min) was placed on the underside of the substrate.
In the first set of experiments, the effect of particle generation was verified. The cross-control experiments were carried out on the diameter and quantity of the generated particles, using different laser fluence and laser pulses with AA5083/6061/7075 specimens. In the next set of experiments, the laser pretreatment method was verified and the experimental conditions and setups were the same as the first experiments. The generated particles form the specimens were examined by an airborne particle counter and analyzed by data platform software. All the experiments were performed in clean room under ISO class 5 atmosphere condition.

3. Results and Discussions

3.1 Variation of the generated particles with laser process parameters
In order to study the effect of different laser fluencies on the number and diameter of generated particles, the experiment was conducted on AA6061 specimen. The results were summarized in Figure 2.

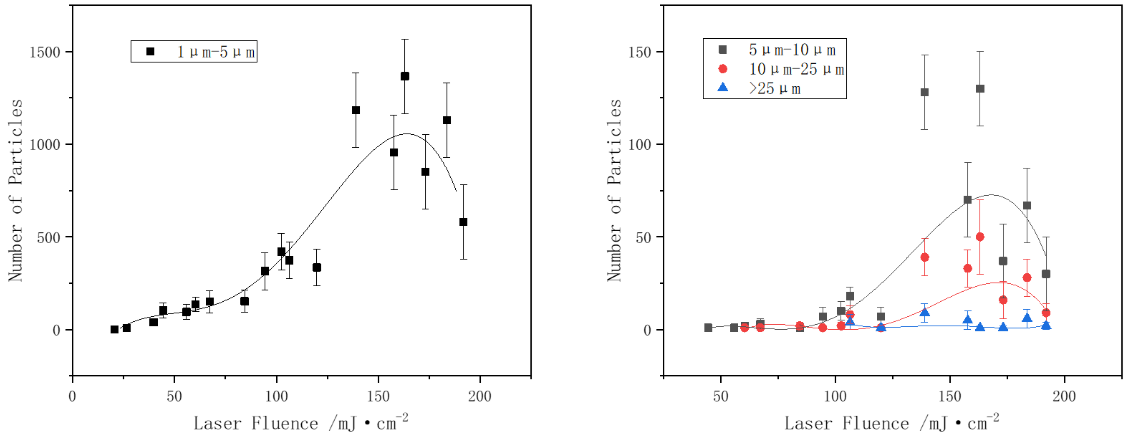

Figure 2. The effect of different laser fluence on the number and diameter of generated particles in AA6061 specimen focused on particles diameter (a) 1μm-5μm (b) larger than 5μm

Figure 2a shows that the number of generated particles is significantly positively correlated with laser fluence. In the operation of high-power laser facilities, particles larger than 1μm can cause obvious laser damage to optical components. So this study focused on particles of this size. Particles of 1μm-5μm accounted for about 90% of the total generated particles. When the laser fluence is 26.64 mJ/cm2, AA6061 specimen began to generate metal particle contamination. Larger particle with a diameter more than 5μm are found for fluencies above 76.54 mJ/cm2.The larger the particle diameter was, the larger the particle generating threshold. Peak number of particles was got at 163.08 mJ/cm2.

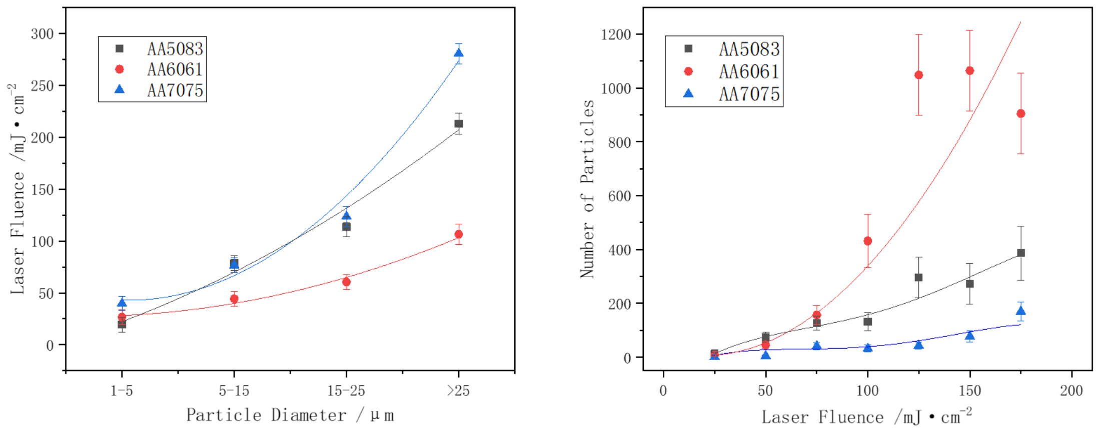

Figure 3. The comparison of (a) generating threshold and (b) particle numbers of AA5083/6061/7075 specimen

As shown in Fig. 3, the overall law of irradiated particle generation characteristics of three materials is consistent. The average initial generating threshold of the three specimens was 28.58 mJ/cm2(Figure 3a). The AA6061 specimen had the lowest generating threshold. For the particles large than 5μm, the generating threshold of 6061 aluminum alloy was only 50.93% -57.23% of the other specimen. For the particles of all sizes, AA7075 specimen had the highest generating thresholds. It can be seen from Figure 3b that the AA7075 was always the specimen with the least number of generated particles at each different laser fluencies.

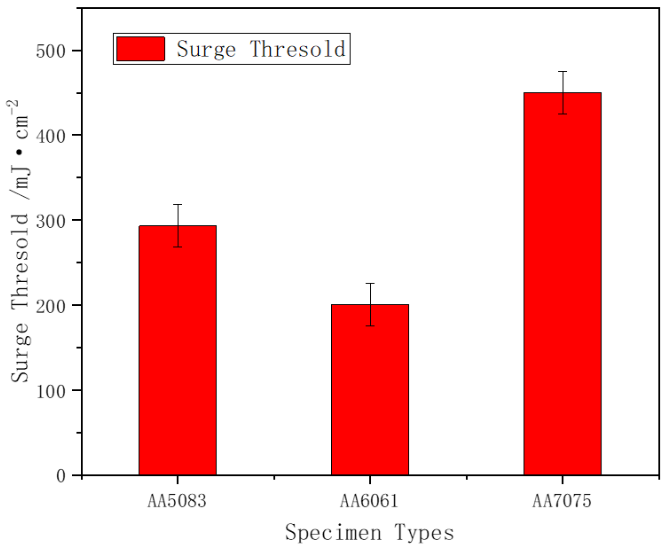

Figure 4. The surge thresholds of AA5083/6061/7075 specimen

During the experiment, it was found that when the laser fluence increased to some certain values, the number of generated particles would sharply increase by one order of magnitude and this growth can be defined as the surge. The surge thresholds of three specimens are shown in Figure 4. The AA7075 specimen had the highest surge threshold about 450 mJ/cm2 and the AA6061 specimen had the lowest surge threshold about 200 mJ/cm2.

The above experiments show that AA7075 specimen had the highest generating thresholds with all particle sizes, the least number of generated particles and the highest surge threshold in three aluminum alloys. These results show that AA7075 specimen has obvious effect to reduce the generated particles irradiated at low fluences.

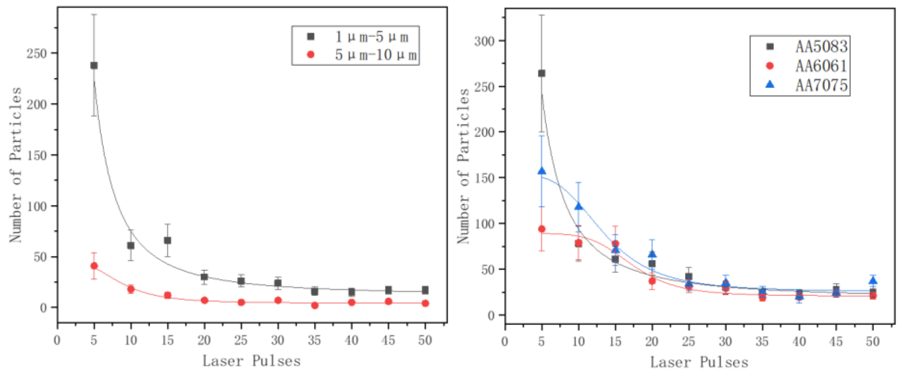

Figure 5. The particle generation of (a) AA6061 specimen and (b) all specimens after multi-shots pulsed laser at 72 mJ/cm2

Previous studies have shown that the scattering laser fluence is always below 100 mJ/cm2 in high-power laser facilities. Therefore, 72 mJ/cm2 was chosen as the preferred laser fluence in the next experiment. As shown in Figure 5a, the diameter of generated particles was concentrated within 5μm in 5 shots. When the laser pulses were issued within 20 shots, the number of generated particles was sharply reduced and was one order of magnitude less than before. This reduction rate was slowed down after 20 shots. After 40 shots, particle number remained substantially stable. The generated particle number was reduced to 3.5% at this time. Figure 5b shows that the generated particle number of three specimens after multi-shots processing was basically the same.

This result is consistent with the practical operation of the high power laser facilities. Characterizatic methods shows that after years of operation of facilities, there are fewer and fewer metal particles on the surface of the optical components. This is not only related to the gradually improving stray light control methods, but also to this multi-shots processing.

3.2 The method of multi-shots laser pretreatment

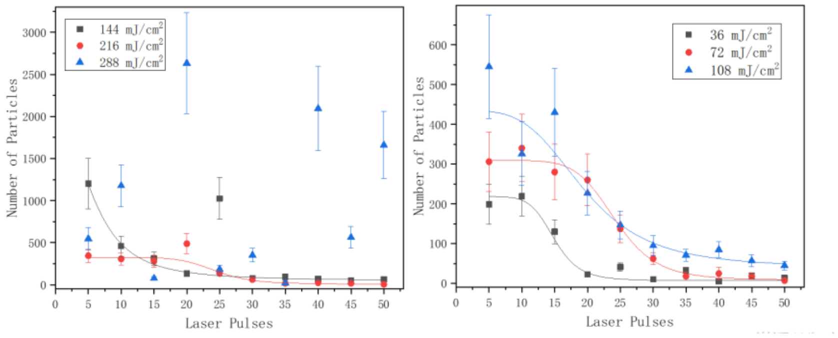

Figure 6. (a) The first shot in laser pretreatment at different fluences (b) The subsequent 40 shots at different fluences of AA6061 specimen

For the AA6061 specimen with a surge threshold of 200 mJ/cm2, single-pulse laser at 144 mJ/cm2, 216 mJ/cm2, and 288 mJ/cm2 was used to irradiate the aluminum alloy surface. And then 40 shots laser were processed at 72 mJ/cm2 (Figure 6a). The laser pretreatment with the first shot at 216 mJ/cm2 which is about 10% higher than the surge threshold, had the least generated particles. The generated particle number gradually decreased with the increase of laser pulses, and eventually stabilized at 40. Under the condition that the laser fluence of the first shot was unchanged, the higher the laser fluence of subsequent 40 shots, the more metal particles were generated (Figure 6b). In this study, 72 mJ/cm2 was chosen as the preferred laser fluence for the subsequent 40 shots to simulate the scattering laser in high-power laser facilities.

After irradiating the aluminum alloy surface with a laser fluence 10% higher than the surge threshold, and then 40 shots laser treatment at preferred 72 mJ/cm2, the number of generated particles is far less than before this processing. This is the laser pretreatment method.

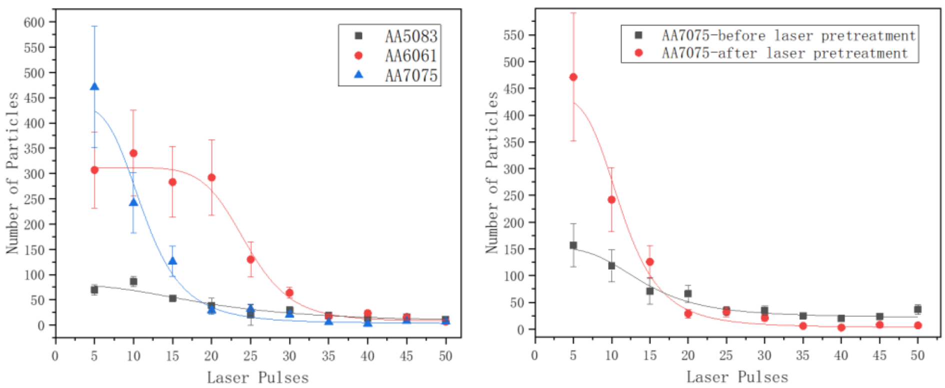

Figure 7. (a) The comparison of laser pretreatment of AA5085/6061/7075 specimens (b) Particle generation of AA7075 before and after laser pretreatment

Figure 7a shows that the AA7075 specimen produced the least number of metal particles about only 10. The particle diameter was less than 5μm. The laser resistance of AA7075 specimen was improved the most by laser pretreatment and it produced the least metal particles. Compared with 40 shots without laser pretreatment at 72 mJ/cm2, this method reduced the generated particles by 76.92% of the AA7075 specimen (Figure 7b).The results shows that this laser pretreatment method can effectively reduce the generation of metal particles.

3.3 Discussions of SEM and XPS Results

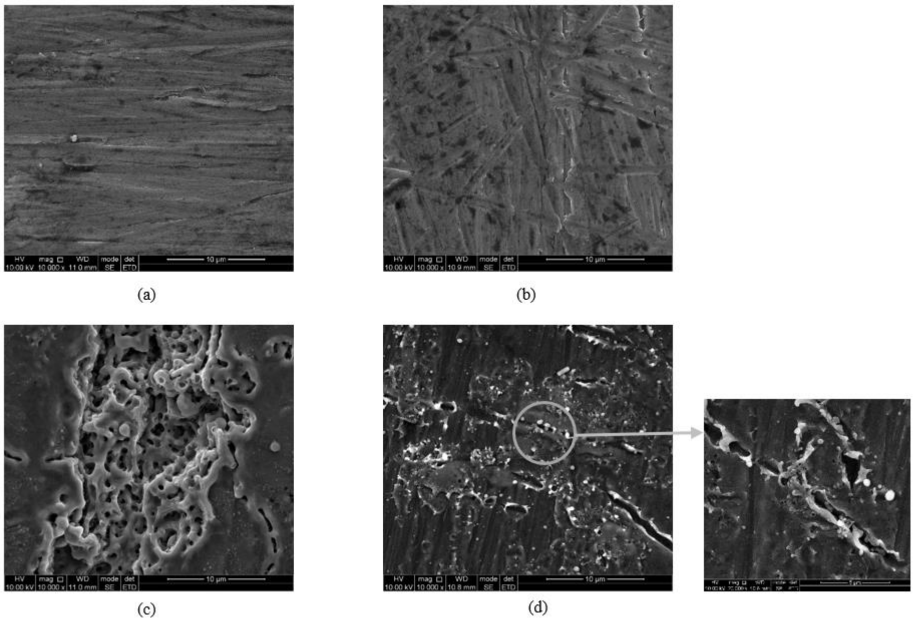

Figure 8. The SEM results of AA7075 specimen at each processing stage

As shown in Figure 8a, the initial aluminum alloy surface was smooth and there were evenly distributed gullies on the surface. Figure 8b shows that when the laser fluence reached the generating threshold, the gullies were more cluttered. Micrometer-sized gaps can be observed. This was caused by detached particles from the surface due to the laser thermal effect. When the laser fluence reached the surge threshold, honeycomb ablative pit and loose structures appeared on the surface (Figure 8c). These structures detached form surface during laser processing. This was what caused the sharply rising in generated particle numbers. Figure 8d showed that after the laser pretreatment, the ablative pits were repaired and bulbous structures were formed due to the plastic extrusion bulge. A large number of dimple and micropores appeared on the surface. The loose structure had been detached from the surface of the aluminum alloy.

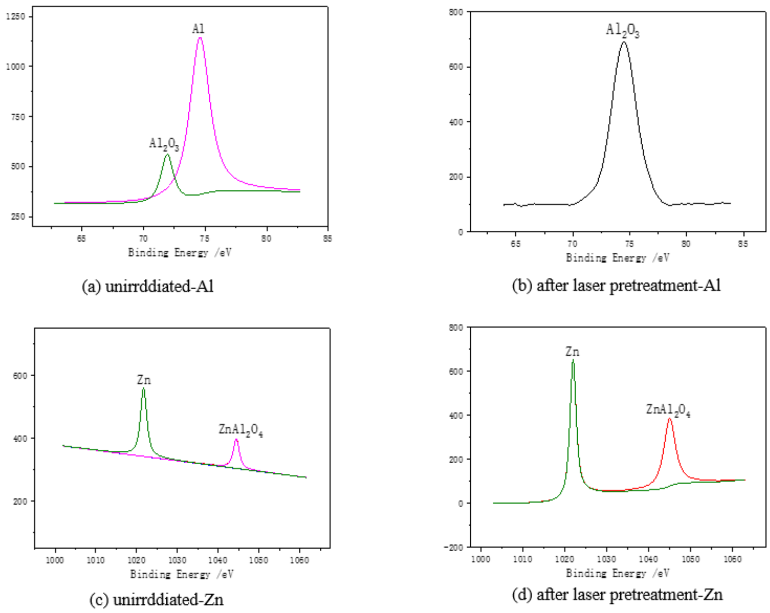

Figure 9. The XPS results of Al and Zn of AA7075 specimen after laser pretreatment

As shown in Fig. 9a and 9b, the aluminum on the sample surface had completely converted into aluminium oxides. Based on the SEM results, it can be found that low fluence pulsed laser caused passivation on aluminium alloys. The aluminium oxide film separated the substrate from the environment and prevented the alloy particles shedding during laser irradiation. 7075 aluminum alloy is based on Al-Zn-Mg-Cu system, in which the zinc content is usually 5%, far more than other alloy composition. Fig. 9c and 9d show that large amount of zinc aluminate was generated on the sample surface after laser pretreatment. The spinel structure of zinc aluminate has excellent mechanical and thermal properties, which effectively reduced the generated particles. This results shows that the laser pretreatment method has obvious effects to improve the laser resistance of aluminum alloy.

4. Conclusion

This work demonstrates that a Nd:YAG laser (τ = 10 ns, λ = 355 nm) was used to simulate the metal particle generation form5085/6061/7075 aluminum alloys surface irradiated by scattering laser in high power laser facilities. Under the laser irradiation at low fluences, 7075 aluminum alloy has the least generated particles. In addition, the results of SEM and XPS confirmed that the multi-shots laser pretreatment method can further reduce the generated particle from aluminum alloy surface in pratical operation in high-power laser facilities.

5. References

[1] Liu B L and Xie F X 2019 Research on position control system of mechanical structure of high power laser device. *Laser Journal*. **40**(7): 152-155.
[2] Patterson B A and Wells M 2003 Analysis of Scattered Light for VISTA. SPIE, 4842: 116-127.
[3] Roni S, Steve B, Michael M, etc. 2003 Stray radiation in airborne FLIR system. SPIE, 4820: 676-687.
[4] Manenkov A A. 2008 Fundamental mechanisms of laser-induced damage in optical materials: Understanding after 40-year research. SPIE, 7132: 713202.
[5] Genin F Y, Michlitsch K, Furr J, et al. 1997 Laser-induced damage of fused silica at 355 and 1064 nm initiated at aluminum contamination particles on the surface. SPIE, 2966: 126-138.
[6] Sommer S C, Stowers I F and Van Doren D E. 2003 Clean construction protocol for the national ignition facility beampath and utilities. *Journal of the IEST*, **46**(1): 85-97.
[7] Pitts J H. 1988 Structural damage and analysis of the NOVA final focusing lenses. *Damage in Laser Materials*, **1**(9): 775-781.
[8] Chi Y M, Gu G C, Yu H J and Chen C Z 2018 Laser surface alloying on aluminum and its alloys: A review. Optics and Lasers in Engineering, 100: 23-37.
[9] Butt M Z, Ammal Javed, M. Waqas Khaliq, et al. 2017 Impact of 1064 nm–10 ns pulsed laser on the surface morphology, structure, and hardness of Pd80Ni20 alloy. *Int J Adv Manuf Technol*, 90:1857–1869.
[10] Wojciech Pakieła, Tomasz Tanski, Mirosława Pawlyta, et al. 2018 The structure and mechanical properties of AlMg5Si2Mn alloy after surface alloying by the use of fiber laser. J. *Applied Physics A*, 124:263.
[11] Yue T M, Yan L J, Chan C P, et al. 2004 Excimer laser surface treatment of aluminum alloy AA7075 to improve corrosion resistance. J. *Surface and Coatings Technology*, 179:158–164.