Atmosphere-dependent Laser Modification and Characterization of Nickel and Titanium Alloys

Boris Rajčić[a], Dubravka Milovanović[a], Sanja Petronić[a]

[a] *Institute of General and Physical Chemistry, Belgrade, Serbia*

This paper presents a comparative study of fast and ultrafast laser processing, nano-(ns), pico-(ps) and femtosecond (fs) pulses, on the surface morphology and properties of Nimonic 263 (nickel-based superalloy) and Ti6Al4V (titanium alloy). Investigations were conducted under varied ambient conditions including air, nitrogen-rich, and argon-rich atmospheres. Observations focus on morphological changes, surface roughness, microhardness, and the formation of laser-induced periodic surface structures (LIPSS). Results indicate that shorter laser pulses (femtosecond and picosecond) provide greater control over micro/nano-scale structuring, with the nitrogen atmosphere enhancing periodic structures and element diffusion. Argon environments produced the most uniform modifications.

Keywords: laser irradiation; material characterization; titanium alloy; nickel alloy; surface modification

1. Introduction

Nickel- and titanium-based alloys such as Nimonic 263 and Ti6Al4V are fundamental to industries requiring biocompatibility, high strength, corrosion resistance, and thermal stability. Their applications span aerospace engines, nuclear reactors, and biomedical devices [1-3]. Laser-based surface engineering offers a versatile approach for enhancing surface performance without bulk material alteration. Particularly, ultrafast lasers provide precise control over energy deposition, enabling minimal thermal damage and the formation of fine surface structures (LIPSS). Nano-, pico-, and femtosecond laser surface modification gives a precise method for enhancing mechanical and optical behaviour of studied alloys [4-5].

This paper gives a comparison of experimental studies focusing on laser-induced modifications on these alloys under various environmental conditions and varying different laser parameters such as laser pulse duration, energy, and count.

2. Results and discussion

Lasers and processing parameters are summarized in Table 1. Experiments were conducted in air atmosphere nitrogen- and argon-rich atmosphere. Characterization techniques used were: SEM, EDS, XRF, profilometry, and microhardness testing.

Table 1. Laser types and processing parameters

Laser	Pulse duration	Wavelength	Pulse energy	Pulse count/ speed
ns TEA CO_2	100 ns	10.6 μm	155-175 mJ	50-2000
ns Nd:YAG	8 ns	1064 nm	7-10 mJ	0.3 mm/min
ps Nd:YAG	150 ps	1064 nm	6 - 30 mJ	10-400
fs Ti:Sapphire	200 fs	775 nm	2.5 – 250 μJ	1-400

All treatments led to crater formation, molten pools, and resolidification. The degree and pattern of modifications varied with laser type. With fs laser, there are generated fine LIPSS with minimal thermal diffusion. Nitrogen atmosphere enhanced ripple definition; air environment led to partial collapse of crater walls at high fluences. Surface roughness and crater depth increased up to 200 pulses, with saturation afterward. With ps laser, we have produced well-defined periodic structures at low pulse energies (6–15 mJ). In nitrogen-rich environments, structured rims and hydrodynamic effects such as crown patterns were observed, especially on Ti6Al4V. Ns laser irradiation caused broader, more uniformly distributed damage with less defined periodicity. Surface modification was more thermally dominated, resulting in higher roughness and deeper imprint areas. XRF analysis shows that laser irradiation slightly altered elemental distribution. Ps laser increased surface Mo and Ti while slightly reducing Co, Fe, Ni, and Cr. These changes were more pronounced in nitrogen atmosphere. After microhardness testing, it was concluded that ps laser-treated areas exhibited significantly higher microhardness compared to ns-treated and untreated surfaces. This was attributed to fine structuring, rapid cooling, and possible nitride formation in nitrogen-rich conditions.

3. Conclusion

Ultrafast laser processing offers significant control over surface structuring and property enhancement of superalloys.

Picosecond and femtosecond lasers induce finer surface features compared to nanosecond lasers.

Environmental conditions critically affect the laser-material interaction; nitrogen and argon atmospheres enhance surface feature definition and promote beneficial compositional changes.

These modifications can be tailored for specific industrial applications like aerospace and biomedical implants.

References

[1] R.C. Reed, The Superalloys: Fundamentals and Applications, Cambridge University Press, Cambridge, 2006.
[2] L.C. Zhang, L.Y. Chen, Adv.Eng.Mat. **21** (2019), 1801215.
[3] Y. Zhu, D. Liu, X. Tian, H. Tang, H. Wang, Mat.Des. **56** (2014), 445-453.
[4] Z. Linm, M. Hong, Ultrafast Sci. **2021** (2021), 9783514.
[5] T.M. Pollock, S. Tin, J.Prop.Pow. **22** (2006), 361-374.

Acknowledgments: The research was supported by the Ministry of Science, Technological Development and Innovation of the Republic of Serbia through contract No. 451-03-136/2025-03/200051.