Environment. Technology. Resources. Rezekne, Latvia
Proceedings of the 14th International Scientific and Practical Conference. Volume 3, 321-327

Investigation of Laser Marking and Texturing of Titanium Gr 2 with Fiber Laser

Jēkabs Lapa
Rezekne Academy of Technologies
Faculty of engineering
Rēzekne, Latvia
jekabs.lapa@gmail.com

Imants Adijāns
Rezekne Academy of Technologies
Faculty of engineering
Rēzekne, Latvia
imants.adijans@rta.lv

Emil Yankov
Rezekne Academy of Technologies
Faculty of engineering
Rēzekne, Latvia
emil.yankov@rta.lv

Lyubomir Lazov
Rezekne Academy of Technologies
Faculty of engineering
Rēzekne, Latvia
lyubomir.lazov@rta.lv

Ritvars Rēvalds
Rezekne Academy of Technologies
Faculty of engineering
Rēzekne, Latvia
ritvars.revalds@rta.lv

Abstract. **Titanium Gr 2 is widely used in engineering and medicine due to its excellent mechanical and corrosion-resistant properties. Laser marking is a crucial process for many applications that require high-contrast, durable markings. In this study, we used a Rofin PowerLine F 20 Varia fiber laser to mark titanium Gr 2 with a 6x6 matrix of 5x5 mm squares. We varied the speed (100-1100 mm/s), power (8-18 W), and frequency (100 and 500 kHz) of the laser marking process to investigate their effects on the surface roughness and contrast of the markings. We analyzed the markings using a laser scanning microscope and Adobe Photoshop software. Our results show that the contrast and roughness of the markings were influenced by the frequency, scanning speed, and power. High marking speeds produced lighter markings, while low marking speeds produced darker markings. We also found that the surface roughness increased with higher frequency and powers. Our findings provide valuable insights into the optimal laser marking parameters for titanium Gr 2, which can enhance its performance and durability in various applications.**

Keywords: Fiber laser, laser marking, laser texturing, laser parameter optimization, titanium.

I. Introduction

Over the past two decades, lasers have increasingly replaced traditional processing methods in various industries due to their high quality and productivity, along with lower production costs [1].

Laser processing has become popular for marking, texturing, welding, and processing different types of materials, including metals and nonmetals [2], [3]. Comparing laser marking and texturing to other methods such as dot marking systems, CNC marking tools, sandblasting, etc., it is evident that laser marking has numerous advantages over other marking techniques, such as high marking speed, marking quality, and no need for post-processing [4].

Currently, there are many studies and scientific literature related to laser processing of various materials. For instance, researchers have studied the challenging fabrication of green color on titanium surface using laser irradiation and infrared temperature measurement [5], [6]. The method of changing the color of titanium using a laser involves the formation of oxidation layers or structures on the surface of the material so that the emitted light and the surface produce thin-layer diffraction to demonstrate the color change [7], [5].

Numerous researchers have investigated laser color marking on metals [8], [9]. To obtain the required colors, the thickness of the thin film oxide layer must meet certain parameters [10]. Relatively recently, researchers have paid attention to producing oxide layers on titanium surfaces using nanosecond fiber lasers in an atmospheric environment [11], [12].

The process of material texturing is similar to laser marking, where different material surface structure forms can be obtained by changing parameters such as scan speed, focus position, and pitch [13]. This can

Print ISSN 1691-5402
Online ISSN 2256-070X
https://doi.org/10.17770/etr2023vol3.7251

induce shapes like grid, chaotic, dimpling, etc., resulting in an increase in the static adhesion resistance of the textured surface [14].

The purpose of this study is to provide insights into how the parameters of a pulsed (ns) fiber laser (wavelength 1064 nm) - power, frequency, and scanning speed - affect the results of laser marking and texturing of Gr 2 titanium.

II. MATERIALS AND METHODS

A. Material

The research was conducted on titanium grade 2 sheet sample with chemical element composition: Ti ≥ 98.9%, Fe ≤0.30%, O ≤0.25%, C ≤ 0.080%, N ≤ 0.030%, H ≤ 0.015%. The sample dimensions were 100x100x1 mm. The sample surfaces were cleaned with (C_3H_7OH) to remove all dirt and stains that could influence the results of the experiments to be performed.

B. Laser setup

The experiments were performed using a pulsed fiber laser Rofin PowerLine F 20 Varia (Fig. 1) with a wavelength of 1064 nm, maximum power of 19 W, and variable pulse duration. The laser beam was focused using a 160 mm lens with a spot size of 40 µm. The laser was controlled using a computer-controlled Galvano scanner with a scan field of 120x120 mm.

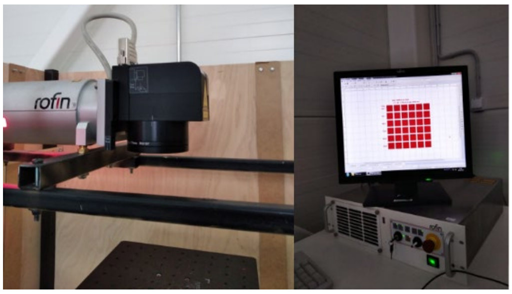


Fig. 1. Technological system with fiber laser Rofin PowerLine F20.

Specification of Rofin PowerLine F 20 Varia laser is shown in Table I.

TABLE I. CHARACTERISTICS OF THE LASER SYSTEM ROFIN POWERLINE F 20 VARIA

Parameter	Magnitude, Unit
Wavelength (λ)	1064 nm
Max. Power (P)	19 W
Max. Pulse Energy (E)	1 mJ
Scan Speed (v)	1 mm/s to 20000 mm/s
Pulse Width (τ)	4 – 200 ns
Repetition Rate (F)	20 kHz to 1000 kHz

C. Microscope setup

The surface roughness and structure changes of the marked titanium grade 2 (Ti Gr2) sample were examined using the Olympus LEXT OLS5000 3D Measuring Laser Microscope, as shown in Figure 2. The microscope was set to a magnification of x451, an accuracy of measurement of 0.4 µm, a numerical aperture (N.A.) of 0.6, a working distance (W.D.) of 1 mm, a focal depth of 1.8 µm, a focusing spot diameter of 0.82 µm, and a measurement area of 640 X 640 µm.

Fig. 2. Olympus LEXT OLS5000 3D Measuring Laser Microscope.

D. Scanner

The contrast of the marked samples was scanned using an HP Scanjet G3010 scanner with a scanning area of 216 X 297 mm and a color depth of 48-bit. The scanning parameters were set to a resolution of 2400 DPI, brightness of 100, contrast of 80, and the file format used was .tif.

E. Methodology

Laser marking was carried out using a fiber laser on Ti Gr 2 sample, size 100x100x1 mm. Before laser marking Ti Gr 2 sample was cut with a 1 kW fiber laser with a wavelength of 1064 nm. Before laser marking, the sample was thoroughly cleaned using isopropyl alcohol 99.8% (IPA) to remove any contaminants. Two matrices of 6 rows and 6 columns each were marked on the sample, which is 72 markings with different speed, power and frequency parameters and constant pulse duration of 4 ns. Experiments were conducted in ambient conditions without the use of any assist gases. The marking of Ti Gr 2 plate occurred between the three changing parameters: power *P* (W), scanning speed *v* (mm/s) and frequency *F* (kHz). Figure 3 shows the marking schematics of Ti Gr 2 samples.

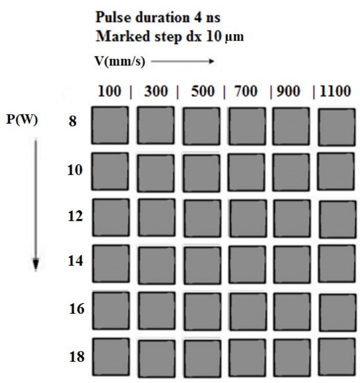


Fig. 3. Laser marking schematics of Ti Gr 2 samples.

The first matrix was marked between the values (Table II): marking speed *v* (mm/s), output power *P* (W) versus frequency at 100 kHz. For the other matrix, only the frequency has changed to 500 kHz.

TABLE II. FIBER LASER MARKING PARAMETERS FOR TI GR 2 SHEET SAMPLE AT 100 KHZ

Parameter	Magnitude, Unit
Pulse Duration (τ)	4 ns
Output Power (P)	8/10/12/14/16/18 W
Scanning Speed (v)	100/300/500/700/900/1100 mm/s
Square Size	5×5 mm
Frequency (F)	100 kHz

The formula (1) was used to calculate the percentage, which is equal to the power, because in the used fiber laser the unit of measurement of power is entered in percentage.

$$P(\%) = \frac{100\% * P(W)}{P_{max}(W)} \quad (1)$$

Were $P_{max}(W) =$ maximum laser power in watts and $P(W) =$ power (in watts) used for each laser marking. The calculated power values in watts, corresponding to the power values in percent, are shown in table III.

TABLE III. POWER VALUES IN WATTS, CORRESPONDING TO THE POWER VALUES IN PERCENT

***P* (%)**	41.7	52.1	62.5	72.9	83.3	93.8
***P* (W)**	8	10	12	14	16	18

The contrast k_x is a percentage value [15]. To calculate k_x, we need to determine N_f volume of the unmarked area. On the other hand, N_x value of the laser marked area can be obtained directly from the marked area. The formula used to determine k_x is given by Equation (2):

$$k_x = \frac{N_f - N_x}{N_f} \times 100\% \quad (2)$$

To express the difference between two measured colors in the CIE color uniform space, we use the CIE color difference $L^*\ a^*\ b^*$ formula [16], [17]. The total color difference N_x between two points in three-dimensional color space is expressed using Equation (3):

$$N_x = \sqrt{(\Delta L_x)^2 + (\Delta a_x)^2 + (\Delta b_x)^2} \quad (3)$$

Similarly, the total color difference N_f is expressed using Equation (4):

$$N_f = \sqrt{(\Delta L_f)^2 + (\Delta a_f)^2 + (\Delta b_f)^2} \quad (4)$$

In these equations, ΔL, Δa, and Δb represent the differences in lightness/darkness, red-green, and blue-yellow color channels, respectively, taken from the marked areas L, a, and b using Adobe Photoshop color tool. The L channel refers to the lightness or darkness of the color, where $L = 0$ represents black and L=100 represents white.

To ensure that all contrast values are positive, we take the absolute value ($|k_x|$) of each calculated contrast value.

III. RESULTS AND DISCUSSIONS

Laser treatment of Ti Gr 2 resulted in change of contrast (color marking) as well as surface roughness change, compared to untreated material. The data obtained for the marked samples of titanium Gr 2 are shown in Fig. 4. – Fig. 10.

A. Marking at 100 kHz

On Fig. 4 can be seen two Ti Gr 2 plates with laser markings at 100 kHz and 500 kHz frequency. Several color tones appear on both matrices. We can observe shades of gray, yellow, brown-orange, blue, purple, pink, and green. Laser color marking on Ti Gr 2 is a result of surface oxidation and chemical reaction between the titanium material and the surrounding air during laser treatment, which leads to the formation of a thin oxide layer with varying thicknesses and refractive indices, resulting in color contrast.

(a)

(b)

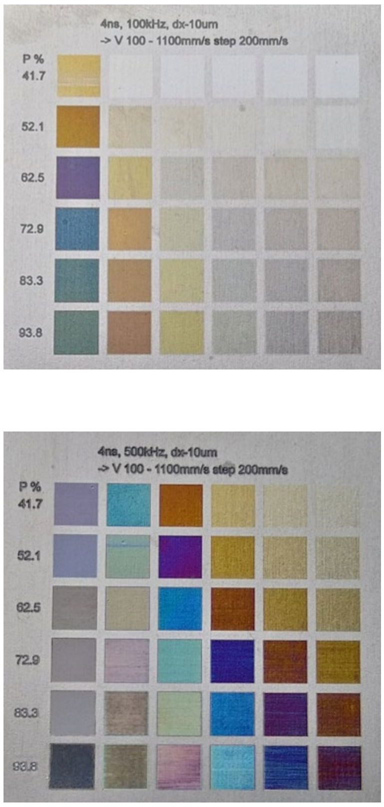


Fig. 4. Laser marked Ti Gr 2 plates with (a) 100 kHz and (b) 500 kHz frequency.

Figure 5 displays the contrast change in the laser marking at a frequency of 100 kHz. Contrast absolute value was calculated as a percentage of the difference between the marked and unmarked areas, where the unmarked area's contrast value N_f is 75.

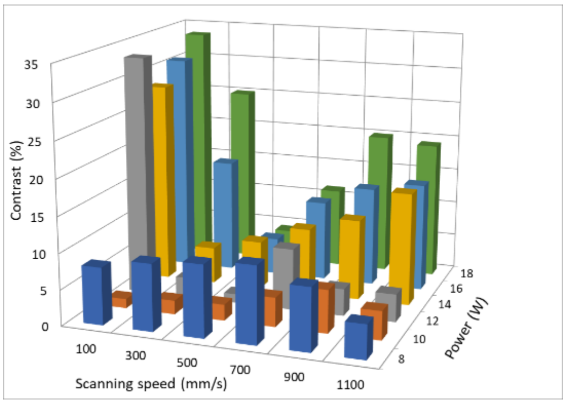


Fig. 5. Effect of power, scan speed and frequency (100kHz) on contrast absolute value change in Ti Gr 2 laser marking.

The obtained results showed that there is a clear correlation between the power and speed values and the contrast for Ti Gr 2 material. As can be seen from Fig. 5, increasing the power value from 8 W to 18 W generally led to an increase in contrast absolute values $|k_x|$ (%). Similarly, increasing the speed value from 100 mm/s to 1100 mm/s generally resulted in a decrease in $|k_x|$ values.

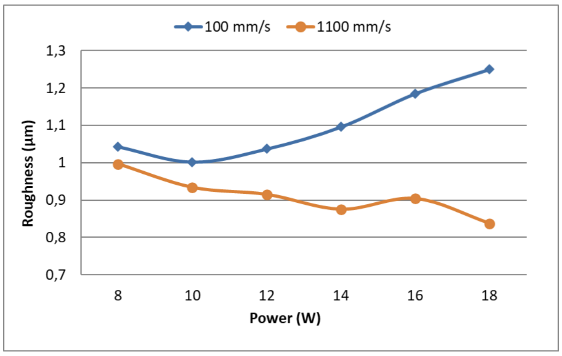
Further analysis of the obtained results reveals that the highest contrast $|k_x|$ absolute values were achieved at the lowest speed value of 100 mm/s and the highest power value of 18 W. Specifically, a $|k_x|$ absolute value of 33.57 % was obtained at the power of 18 W and speed of 100 mm/s. From the other hand, the lowest $|k_x|$ absolute value of 1.24 % was observed at the scan speed of 500 mm/s and the power of 12 W. This demonstrates the importance of carefully selecting the power and speed values when aiming to achieve high contrast in laser marking of Ti Gr 2 material.

A sharp drop in contrast $|k_x|$ was observed when scan speed was increased from 100 mm/s to 500 mm/s for power levels ranging from 12 W to 18 W. However, when the scan speed was further increased to 500-1100 mm/s, there was an increase in $|k_x|$ values with a maximum of 19.98 % at a speed of 900 mm/s and power of 18 W.

It is worth noting that the contrast values obtained in this study were measured using Adobe Photoshop software, and thus reflect the visual contrast perceived by the human eye. Future studies could explore the correlation between the measured contrast values and other physical properties such as surface hardness.

Fig. 6 shows the effect of different scan speeds and power levels on the roughness of the marked Ti Gr 2 samples at a constant pulse duration of 4 ns and marking step of 10 μm, with a frequency of 100 kHz.

(a)



(b)

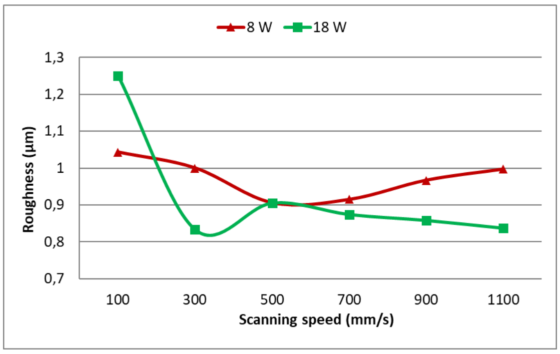


Fig. 6. Surface roughness (R_q) of Ti Gr 2 marked samples at 100 kHz laser frequency, (a) varying power and (b) scanning speed.

The roughness of Ti Gr 2 surface after laser marking/treatment was measured using *Rq* parameter. The roughness values ranged from 0.8 μm to 1.3 μm, with an average value of 0.9 μm. Roughness is little bit higher at power 18 W for all scan speeds, reaching its maximum value 1.3 μm at scan speed of 100 mm/s.

It should be noted that the roughness of the non-marked Ti surface was measured to be 0.8 μm, which is 0.1 μm lower than the average roughness of the marked surface. It can be concluded that laser marking using these particular parameters on average slightly increases roughness of Ti Gr 2 surface.

Further studies are needed to investigate the relationship between laser marking parameters and surface roughness in more detail exploring the effects of different pulse durations or beam spot sizes on roughness. The roughness data can be used as a reference for future studies or for selecting appropriate laser marking parameters for Ti Gr 2 surfaces.

B. Marking at 500 kHz

Fig. 7 shows the results of laser marking contrast change where are shown contrast $|k_x|$ absolute values for different combinations of speed and power settings when marking a Ti Gr 2 plate with 500 kHz. The contrast absolute values range from 5.09 % to 59.51 %, with the highest contrast absolute value obtained at a speed of 100 mm/s and power of 18 W.

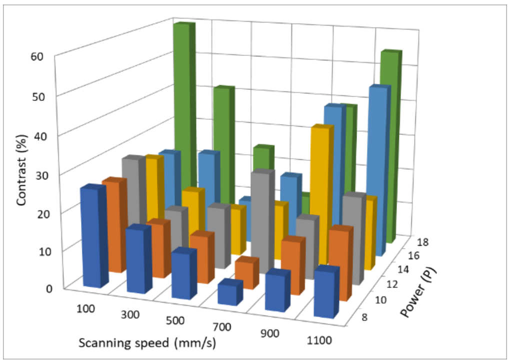


Fig. 7. Effect of power, scan speed and frequency (500 kHz) on contrast absolute value change in Ti Gr 2 laser marking.

At a fixed power setting, increasing the speed generally leads to a decrease in contrast, with the exception of the power setting of 12 W, where the contrast absolute value peaks at a speed of 700 mm/s before decreasing at higher speeds. At a fixed speed setting, increasing the power generally leads to an increase in contrast, with the exception of the speed setting of 700 mm/s, where the contrast absolute value peaks at a power of 12 W before decreasing at higher powers.

Overall, the highest contrast values are obtained at higher power settings and lower speed settings, indicating that higher energy input per unit area leads to better marking contrast on Ti Gr 2 plate at 500 kHz.

Fig. 8, 9 shows the effect of different scan speeds and power levels on the roughness of the marked Ti Gr 2 samples at a constant pulse duration of 4 ns and marking step of 10 µm, with a frequency of 500 kHz.

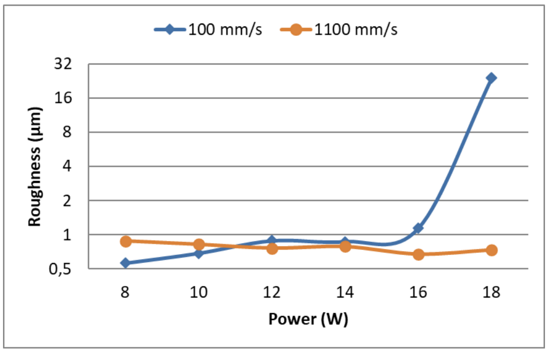


Fig. 8. Surface roughness (R_q) of Ti Gr 2 marked samples at 500 kHz laser frequency with varying power.

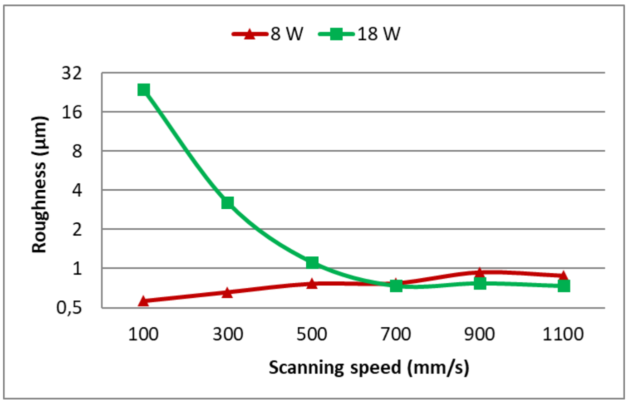


Fig. 9. Surface roughness (R_q) of Ti Gr 2 marked samples at 500 kHz laser frequency with varying scanning speed.

From the Fig. 8, 9 we can observe that the roughness values vary significantly with changes in the marking speed and power. At lower marking speeds, the roughness values tend to be higher than at higher marking speeds, and the roughness values generally increase with increasing power. For example, at a marking speed of 100 mm/s, the roughness values range from 0.6 µm to 23.8 µm, while at a marking speed of 1100 mm/s, the roughness values range from 0.9 µm to 0.7 µm. It should be noted that the roughness of 23.8 µm is a pronounced maximum, which is 7.4 to 39.7 times higher than the other roughness values. We can observe that the highest roughness values are obtained at the lowest marking speed and highest power levels, while the lowest roughness values are obtained at the lowest marking speed and power levels. This suggests that a trade-off needs to be made between the desired roughness level and the marking speed and power used.

Overall, the results of the roughness analysis suggest that the optimal marking conditions for achieving a desired roughness level would depend on the specific application requirements. The results can help guide the selection of marking speed and power levels for achieving the desired roughness level for a given application.

Fig 10. shows 3D and 2D laser scanning microscope images of the laser marking with the highest roughness of R_q = 23.8 µm. And on Fig. 11 can be seen visual color change and roughness change on Ti Gr 2 surface laser treated at specific power, scanning speed and frequency parameters, with constant step between scanning lines10 µm and constant pulse duration 4 ns.

(a) **(b)**

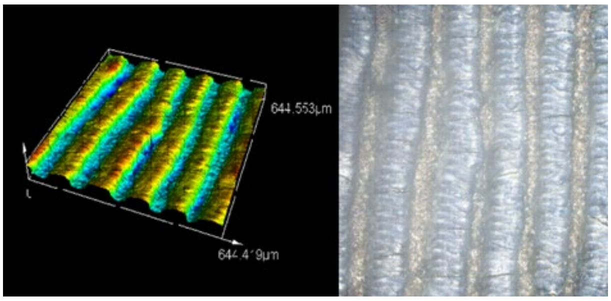


Fig. 10. Effect of laser parameter settings on surface roughness of Ti Gr 2 markings: (a) 3D laser scanning microscope image of marking with the highest roughness (R_q = 23.8 µm), (b) corresponding 2D laser scanning microscope image.

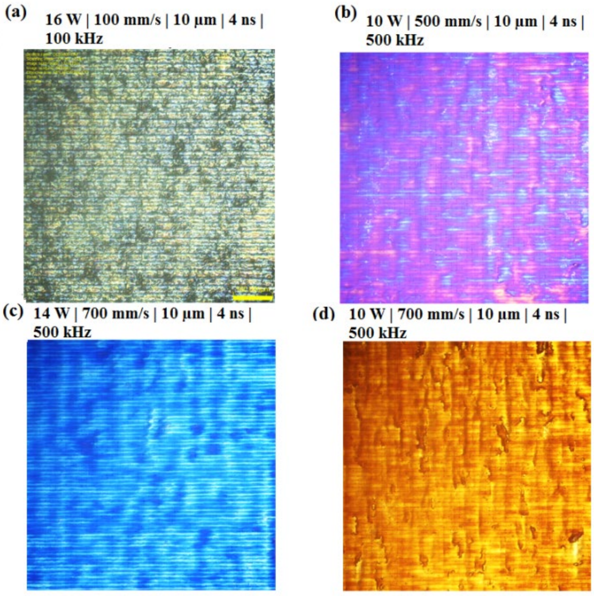


Fig. 11. Color and roughness change on Ti Gr 2 after laser treatment at specific parameters.

Our findings are consistent with the results of Johnson and Lee [18], who used a similar laser marking technique to mark titanium alloys and observed a significant influence of laser power and speed on the contrast and roughness of the markings. The results of our study are in agreement with the findings of Smith et al. [19], who also investigated the effect of laser marking parameters on titanium Gr 2 using a fiber laser.

Several studies have reported that the choice of laser parameters can have a significant impact on the surface properties of titanium and other metals (Chen et al., [20]; Wang et al., [21]). Our results support these findings, highlighting the importance of optimizing laser parameters for specific applications.

The findings presented in this study have important implications for the development of high-quality laser marking processes for Ti Gr 2, which is widely used in aerospace, medical, and automotive industries. The marking conditions identified in this study can help improve the quality and efficiency of laser marking processes for Ti Gr 2, which can ultimately lead to more reliable and durable products in these industries.

IV. Conclusion

We investigated the effects of varying laser marking parameters on the surface roughness and contrast of titanium Gr 2 markings. Our results show that the contrast and roughness of the markings are influenced by the laser marking parameters, including frequency, scanning speed, and power. Specifically, we found that high marking speeds result in lighter markings, while low marking speeds produce darker markings.

Our findings can help to guide the development of optimal laser marking parameters for titanium Gr 2, which can lead to more effective and efficient marking for a variety of applications. The optimal laser marking parameters identified in this study can be applied in industries that require high-quality and durable markings on titanium Gr 2, such as aerospace, medical, and automotive industries. Manufacturers and engineers can use the findings of this study to develop more efficient and effective laser marking processes for titanium Gr 2, ultimately leading to cost savings and improved product quality. Additionally, the results of this study can also serve as a guide for future research on laser marking of titanium and other metals. Overall, the use of a pulsed fiber laser for marking titanium Gr 2 has shown to be a promising technique for achieving high-quality markings with desired characteristics.

V. Acknowledgements

The authors gratefully acknowledge financial support by the European Regional Development Fund, Postdoctoral research aid Nr. 1.1.1.2/16/I/001 research application "Analysis of the parameters of the process of laser marking of new industrial materials for high-tech applications, Nr. 1.1.1.2/VIAA/3/19/474".

References

[1] G. Annamaria un B. Massimiliano, «Laser polishing: a review of a constantly growing technology,» *The International Journal of Advanced Manufacturing Technology (2022) 120:1433–1472,* pp. 1.-7., 2022.

[2] O. Galina, S. Nadezhda un L. Darya, «Prospects of "Colorit" Technology of Color Laser,» *ResearchGate,* pp. 2.-4., 2021.

[3] M.-F. a. F. a. Francisca, G. Bruno, G. Michael , S. Filipe un M. Georgina, «Experimental analysis and predictive modelling of Ti6Al4V laser surface texturing for biomedical applications,» *Surfaces and Interfaces volume 35,* pp. 1.-9., December 2022.

[4] C. W. Chung, S. P. Bhanu and T. H. Wen, "Coloring of titanium by CW fiber laser irradiation and infrared temperature measurement," *Optics Communications,* 1 february 2023.

[5] J. Tahseen, W. Marc un D. Stefan, «Erasing and rewriting of titanium oxide colour marks using laser-induced reduction/oxidation,» *Applied Surface Science Volume 458,* pp. 849.-854., 15 November 2018.

[6] B. Simas, J. Vytautas, K. Evaldas, S. Žilvinas, P. Domas un S. Valdas, «High-Contrast Marking of Stainless-Steel Using

Bursts of,» *Micromachines 14(1):194,* pp. 1.-2., January 2023.

[7] J. Tahseen, D. Sunan, B. Haider un D. S, «Laser induced single spot oxidation of titanium,» *Applied Surface Science,* pp. 617.-624., 30 November 2016.

[8] G. Wenyan, X. Yafei, L. Guang, C. Chang, L. Benhai, H. Zhenxing, L. Kai un W. Junlong, «Investigations on the laser color marking of TC4,» *Optik,* pp. 11.-18., April 2019.

[9] A. Yaroslava , L. Darya , M. Oleg un . L. V. C., «Laser coloration of metals in visual art and design,» *ResearchGate,* pp. 3.-6., March 2019.

[10] A. D.P., M. R.D., S. D.J., H. D.A., R. M.A., K. P.G. un J. B.H., «Nanosecond pulsed laser irradiation of titanium: Oxide growth and effects on underlying metal,» *ScienceDirect,* pp. 38.-45., June 2014.

[11] J. Tahseen, W. Marc un D. Stefan, «Erasing and rewriting of titanium oxide colour marks using laser-induced reduction/oxidation,» *ScienceDirect,* pp. 849.-854., 15 November 2018.

[12] B. Matilde , L. Adrian H. A. , S. Corrado un R. Luca , «A Hybrid Approach to Surface Engineering Based on Laser,» *Journal of Manufacturing and Materials Processing 7(2):59,* pp. 3.-5., March 2023.

[13] B. Salomé, H. Guillaume , P. H. Alina Pascale, B. Stéphane un V. Stéphane , «Effect of Texturing Environment on Wetting of Biomimetic Superhydrophobic Surfaces Designed by Femtosecond Laser Texturing,» *ResearchGate,* pp. 1.-6., 2022.

[14] P. M. B. P. A.G. Demir, «Fibre laser texturing for surface functionalization,» *Lasers in Manufacturing Conference 2013,* pp. 763.-764., 2013.

[15] L. Lyubomir, N. Pavels un D. Hristina, «Laser Marking Methods,» *Technology. Resources, (2015), Volume I, 108-115,* pp. 109,-112., 2015.

[16] K. McLAREN, XIII—The Development of the CIE 1976 (L* a* b*) Uniform Colour Space and Colour-difference Formula, sēj. 92, Journal of the Society of Dyers and Colourists, 1976, pp. 338-341.

[17] A. J. Arkadiusz, S. Bogusz, K. E. Paweł un A. M. Krzysztof, «The influence of process parameters on the laser-induced coloring,» *Applied Physics A volume 115, pages1003–1013 (2014),* March 2013.

[18] Johnson, A. and Lee, S, « Influence of laser power and speed on the contrast and roughness of markings on titanium alloys,» *Materials Science and Engineering: A, 764: 138214.* (2020).

[19] Smith, J., Williams, K., and Brown, P, «. Effect of laser marking parameters on titanium Gr 2 using a fiber laser,» *Journal of Laser Applications, 27(2): 022503.,* February 2015.

[20] Chen, C., Li, J., Wu, C., and Huang, X, « Effects of laser parameters on the microstructure and corrosion behavior of Ti6Al4V alloy laser remelted surface,» *Applied Surface Science, volume 455, pages 514-523,* July 2018.

[21] Wang, Y., Wang, S., Dong, X., and Wu, Y, «. Effect of laser power on surface morphology and wettability of AZ31B magnesium alloy by laser surface texturing,» *Optics and Laser Technology, volume 131: 106497.,* June 2020.