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Review

Influence of Laser Modification on the Surface Character of Biomaterials: Titanium and Its Alloys—A Review

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Abstract: Laser surface modification is a widely available and simple technique that can be applied to different types of materials. It has been shown that by using a laser heat source, reproducible surfaces can be obtained, which is particularly important when developing materials for medical applications. The laser modification of titanium and its alloys is advantageous due to the possibility of controlling selected parameters and properties of the material, which offers the prospect of obtaining a material with the characteristics required for biomedical applications. This paper analyzes the effect of laser modification without material growth on titanium and its alloys. It addresses issues related to the surface roughness parameters, wettability, and corrosion resistance, and discusses how laser modification changes the hardness and wear resistance of materials. A thorough review of the literature on the subject provides a basis for the scientific community to develop further experiments based on the already investigated relationships between the effects of the laser beam and the surface at the macro, micro, and nano level.

Keywords: laser modification; titanium; titanium alloys

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1. Introduction

Surface modifications of materials provide the base for achieving specific material properties for specific applications. The main advantage of laser surface modification is the ability to improve the properties of different materials [1,2]. In addition, the precision, elasticity, the possibility of parameters control, and the repeatability of this process are indicated as an advantage, as is the small heat-affected zone resulting from the modification [3,4]. Because of the high degree of process sophistication, it is also possible to carry out the process without direct human intervention, thus reducing the risk of negative effects on the body [5].

Researchers mainly use lasers such as a femtosecond laser [6], Nd: YAG laser [7–10], CO_2 laser [11], diode [12,13], and fiber laser [14]. Firstly, they provide the possibility to carry out modification processes by adding a coating of the same or another material. Moreover, they are used for modifications with no further addition of materials [1]. Figure 1 presents a classification of laser machining based on an increase or no increase in material. This article is primarily concerned with laser remelting and texturing, as these two techniques are the most commonly used in the modification of biomaterials. Laser remelting is a technique based on remelting the surface of a material to change its morphology and structure without a specific modification objective, to generally improve the properties affected by a laser beam or, for example, when there is talk of modifying the density of the material or the hardness [7,15–17]. Laser texturing involves melting the material and then cooling it to produce a specific pattern on the surface of the material [18]. A combination of laser hardening and laser texturing is also found in the literature [19]. Laser hardening is a technique aimed at improving the hardness of materials using a laser beam. Furthermore, it has the advantage of being able to increase the wear resistance and improve fatigue properties.[20] Surface modification with no addition of a material, which will be discussed in the following work, directly affects a change in wettability and roughness, corrosion resistance, hardness of the material, and wear resistance. Laser modification is closely related to a change in the surface microstructure and influences the roughness and wettability of materials [21–24]. The advantages of using lasers to modify biomedical materials are the ability to control the effect of heat on the surface structure of the materials due to the local action of a laser pulse on the surface, the small heat-affected zone, and the fact that the process is clean and does not cause material loss [25,26].

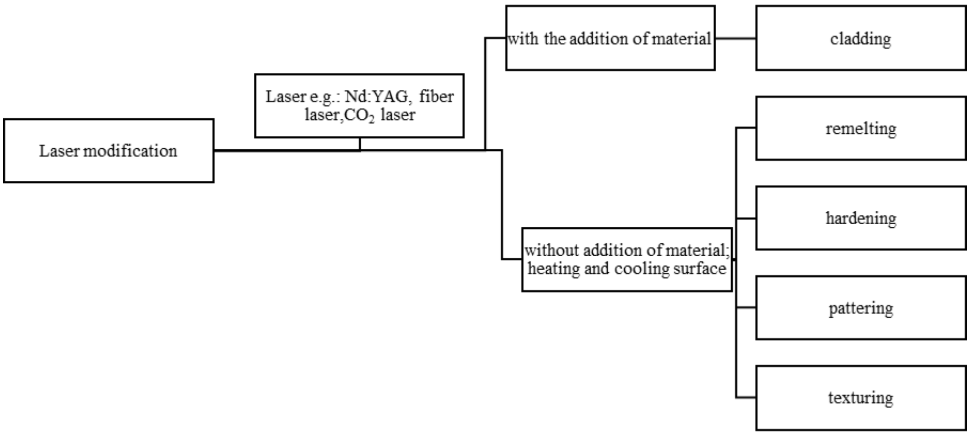

Figure 1. Graphic interpretation of laser modification possibilities based on [1,13,20–22].

The process of the heat treatment of materials by laser is mainly related to the treatment of metallic materials such as aluminum, steel, and its alloys, as well as titanium [2,3,27,28]. Many research efforts are currently focused on gaining a thorough understanding of the properties of titanium and its alloys. Further, efforts are being made to improve these properties to produce a material dedicated to applications.

Titanium and its alloys are widely used in various industries due to their low density. This family of materials has its uses in the manufacture of parts for motorcycles, and sports vehicles to reduce their weight [29,30]. In the aerospace industry, these materials are the third group of materials, after nickel-based materials, in terms of their frequency of use, not only because of their low density, but mainly because of their resistance to corrosion and high temperatures (e.g., alpha alloys and α/β alloys) [31–33]. Considerable attention is given to this material when it comes to medical applications [34,35]. In applications in the field of dental implantology, titanium alloys are used for the production of dental crowns and bridges primarily due to the reduced risk in an allergic reaction and they have a beneficial effect on the process of osseointegration [36,37]. The use of titanium and its alloys is based on its high corrosion resistance, better than steel and cobalt–chromium alloys, owing to the properties of self-assimilation, which are beneficial due to the environment of the body in which the implants are placed [38–41]. In the case of titanium and its alloys, it is said to have little effect on the human body. Pure titanium is a biocompatible material, as are all of its alloys. The alloying elements used to produce titanium alloys, however, do pose a problem, but it should be noted, that titanium and its alloys have hemolytic indices below a value that would indicate the possibility of the formation of embolisms or clots as a result of the presence of this material in the body [42]. Studies by Chen et al. indicate that the presence of vanadium and aluminum in the human body leads to disorders of the nervous system, brain diseases, and circulatory diseases, while also affecting the softening of bone tissue; however, it is indicated that alloys containing aluminum and vanadium (α + β alloys) have mechanical properties on the same level as β alloys. In implantology, aluminum–vanadium alloys are used primarily to produce fracture fixation plates, spinal column components, and connecting elements such as rods, wires, and screws [43]. Review papers over the years related to modifications using laser beams have reported on the benefits of modification for industrial applications (matrix-enhanced laser modification) [44], but they mainly confirm the benefits for biomedical applications [45,46]. Paper [45] focuses on the effect of laser surface texturing on the antimicrobial properties and biological activity of titanium, while a 2005 article [46] provides an overview of the possible types of surface modifications available for various biomaterials and discusses in detail laser modification in the context of the biocompatibility of the modified material. The present review focuses on the mechanical properties of the surface of titanium and its alloys after laser modification. Attention is paid to the properties directly related to the requirements for biomedical materials, such as an adequate material hardness, wear, corrosion resistance, and affinity of the modified surface to bone-forming cells.

A literature review on the effects of laser modification on titanium and its alloys was conducted to present the current state of the art in this field and to highlight the topicality of the problem of the laser modification of titanium and its alloys for biomedical applications due to the requirements that are placed on biomaterials.

2. Methods

This systematic review used the databases: ResearchGate, Science Direct, and Scopus. Google Scholar was also used to analyze the trends in the laser modification of titanium and its alloys. The searching strategy was based on the "laser modification", "laser treatment", "laser remelting", "laser surface modification of titanium and its alloys", and "modification of titanium and its alloys" terms. A bibliography of 175 literature references was collected and extracted from over 200 collected papers. Figure 2 shows the number of articles from each year. The literature review was based mainly on works from 2019 to 2022, which allowed us to discuss issues according to the current state of knowledge on the laser surface modification of titanium and its alloys for selected parameters and properties. The paper discusses the effect of the laser treatment of titanium and its alloys on the surface roughness and wettability, corrosion resistance, and hardness with the indications of micro and macro hardness and wear resistance.

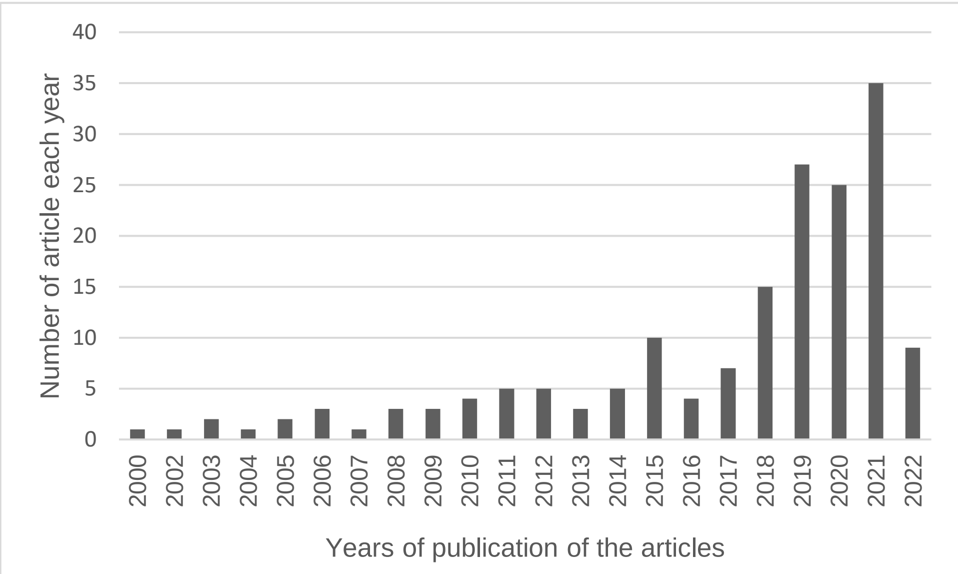

Figure 2. Distribution of the number of articles used per year.

3. Roughness and Wettability

Roughness and surface wettability are very often compared by authors to determine the relationship between these properties [47,48]. The study of these parameters in the case of titanium modifications is very important due to the use of titanium in biomedicine. The evaluation of the roughness parameter is important because an increase in this index has a positive effect on the cell adhesion during osseointegration and on the connection between the bone and an implant [49]. The use of titanium and its alloys in biomedicine is indicated for the manufacture of artificial hip joints, artificial knee joints, bone plates, fracture fixation screws, prosthetic heart valves, pacemakers, and the production of artificial hearts [50,51]. Depending on the area of aspiration of titanium and its alloys, a different surface roughness is required of a biomaterial. For example, heart valve implants, the artificial heart, and other components of the circulatory system must be made of a medium to low-roughness titanium to avoid the formation of areas where blood cells could agglomerate and form blockages, thus stopping the blood flow [52]. In addition, titanium itself possesses anti-thrombogenic properties, and for implant applications, it is necessary to improve the properties of the structure. In the case of osseous dental implants, it is said that components with a high degree of surface roughness are necessary due to the osseointegration process that occurs. An increase in the surface roughness is associated with an increase in the growth surface of osteoblasts and protein polyfusion [53]. Menci et al. [24] point out that laser modification with different types of lasers (e.g., a fiber laser or Nd: YAG laser) is necessary, as the hip implants in question are composed of several elements and each part must have different surface properties. The acetabulum and femoral stem need to be rougher to stimulate bone osseointegration, while the femoral head and distal part of the femoral stem need to be smoother to minimize wear.

In paper [49] it was shown that the roughness of the pore walls created by laser modification was characterized by the roughness parameters, Sa and Sq, with a higher value than on the inter-pore surfaces. The values of Sa and Sq for the inter-pore surfaces were 0.029 μm and 0.04 μm, respectively, while those for the pore walls were 0.126 and 0.149 μm, respectively. The authors concluded from their studies on bone deposition that a higher pore roughness improves the migration of bone-forming cells and also increases the possible surface area for osteoblast attachment to the implant. Furthermore, a high surface roughness is desirable due to increased biointegration and a decreased risk of implant rejection in the body [8].

In papers [8,54–60], an Nd: YAG laser was used to modify titanium alloys and pure titanium. In Table 1, the Nd: YAG laser operating parameters are presented for the literature reviewed subject. In the study, the Nd: YAG laser modification was performed for different laser operating parameters. The effects of varying laser operating parameters on the surface roughness and wettability, which are directly related to the phenomenon of bone cell adhesion, were investigated in a study from 2013, where Györgyey et al. showed [58] a decrease in the R_a roughness parameters using a frequency-doubled Q-switched Nd: YAG laser and a KrF excimer laser. In a 2020 editorial [8] it was observed that the modification of the titanium alloy Ti13Nb13Zr and pure titanium CP-Ti using an Nd: YAG laser caused an increase in the surface roughness. In addition, it was shown that the higher the laser power, the higher the roughness parameters. Additionally, in research work [8] it was pointed out that titanium alloys were rougher than pure titanium before and after laser treatment. Research of [57,61–63] also confirmed that laser modification, regardless of the type of laser, along with increasing the laser parameters, increased the roughness. In paper [57] it was shown that laser processing increased the roughness parameters by approximately 2.8 to 7.5 times at different frequencies relative to the native material. AFM surface texture tests at 10 Hz and 7 Hz successively yielded R_a parameters of 394.35 nm and 279.53 nm, respectively, while this parameter for the reference sample of the Ti6Al4V titanium alloy was 127.20 nm [57].

Table 1. Parameters of Nd: YAG laser modification to improve the roughness of titanium and its alloys.

Laser	Material	Environment	Laser Output Energy	Voltage	Laser Pulse Duration	Irradiation Time	Scanning Speed	Frequency	Average Expansive Area	Fluency/Power	Shot of Pulses	Roughness Parameters	Reference
Nd: YAG	Ti13Nb13Zr and CP-Ti	air/argon	5;30 mJ	-	150 ps	5s	-	10 Hz	-	-	50	(Table 2)	[8]
	Ti15Mo and cpTi grade 2	-	-	-	-	-	0–200 mm/s	20–35 Hz	14 mm²	1.9 J/cm³	-	-	[54]
	technically pure VT-1–00 titanium	Air	-	250–400 V	3–10 ms	-	-	1–5 Hz	-	-	1–5	R_a = 3.95 μm R_z = 21.2 μm R_{max} = 29.01 μm S_m = 91 μm	[55]
	Ti6Al4V	-	-	-	-	-	30 mm/min	-	-	200 W	-	R_a = 0.45 μm	[56]
	Ti6Al4V	Argon	-	-	7 ms	-	1 mm/s	1, 3, 5, 7, 10, 15, 20 Hz	-	average power 300 W; peak power 2.1 kW	-	R_a for 10 H z = 0.394 μm R_a for 7 H z = 0.127 R_a μm	
	CP4) Ti rods	Air	-	-	-	-	-	-	-	1–1.5 J/cm³	200, 300, 400	-	[58]
	Ti6Al4V	Air	95 mJ	-	-	120 ns	-	10 Hz	-	0.95 W	-	-	[59]
	Ti45Nb	Air, argon, nitrogen	-	-	150 ps	5 ns; 15 s	-	10 Hz	7.1×10^{-4} cm²	0.13–0.38 J/cm²	50, 150	(Table 2)	[60]

Table 2. Surface roughness depended on the laser modification environment [8,60].

Sample [60]	**Ti4Nb**											
Laser modification environment	Argon				Air				Nitrogen			
Laser modifications parameters	5 mJ 50 pulses	5 mJ 150 pulses	15 mJ 150 pulses	15 mJ 150 pulses	5 mJ 50 pulses	5 mJ 150 pulses	15 mJ 150 pulses	15 mJ 150 pulses	5 mJ 50 pulses	5 mJ 150 pulses	15 mJ 150 pulses	15 mJ 150 pulses
Surface roughness [μm]	1.026	2.053	1.414	3.062	0.551	0.921	0.884	0.949	0.839	1.148	0.647	0.804
Sample [8]	Ti13Nb13Zr											
Laser modification environment	Air						Argon					
Laser modifications parameters	5 mJ 5 s			30 mJ 5 s			5 mJ 5 s			30 mJ 5 s		
Surface roughness [μm]	0.428			0.988			0.701			1.366		
Sample [8]	CP-Ti											
Laser modification environment	Air						Argon					
Laser modifications parameters	5 mJ 5 s			30 mJ 5 s			5 mJ 5 s			30 mJ 5 s		
Surface roughness [μm]	0.258			0.931			0.927			1.842		

The references state that the laser treatment of titanium surfaces allows for controlling the roughness parameters, R_a, R_z, and R_{max}, in a wide range [55]. The use of a modern fiber laser engraving method [64] allowed the achievement of a surface with a higher roughness than the Ti6Al4V native material. Meanwhile, comparing the results of the roughness measurements at different laser operating parameters, it was observed that with an increase in the laser operating parameters (e.g., groove distance and frequency), there was a decrease in the value of the roughness and an increase in the value of the wetting angle, which was associated with the determination of the surface of the samples as hydrophobic.

Studies [8,60,65]also indicate that the operating environment of the Nd: YAG laser affects the surface roughness and morphologies. The results of EDS [8] have shown that the presence of argon affects the reduction of oxygen molecules for both commercially pure titanium and Ti13Nb13Zr titanium alloy samples; however, the modification carried out in the presence of air caused a strong passivation of the coating and, thus, increased the amount of oxygen on the surface, while the surface roughness for the modified surfaces in the presence of air was lower. Conducting the modification in the presence of argon for each parameter variant results in the roughest surface (Table 2). The laser modification in a nitrogen environment for low power and number of pulses presented in work [60] showed a higher roughness than for the same modification in the presence of air, while in the case of a modification in the presence of argon the modified surfaces—for different laser powers of 5 mJ and 15 mJ and the number of pulses of 50 and 150—were characterized by the highest roughness among all the modified surfaces. The conclusions in [60] are confirmed in [65], where the reason for the lower surface roughness after modification in a nitrogen environment was due to the formation of titanium and nitrogen compounds and the formation of a smaller heat-affected zone. The authors of that article also indicated that for a smaller number of pulses performed, the surface roughness was lower.

Lawrence et al. [56] 2006, presented the idea that laser processing increases the roughness parameters and improves the surface wettability. In Table 3, the literature on the results of the influence of a laser treatment on the character of the surface wettability is summarized. Menci et al. [24] searched for a direct relationship between the contact angle and the Sa parameter for Ti11.5Mo6Zr4.5Sn titanium alloy samples modified by an Nd: YAG laser and fiber laser for different parameters. Wenzel's claim was referred to, which states that increasing the roughness parameter (r) increases the wettability of the surface (where θy is the contact angle of an ideal flat surface and θw is the contact angle of a rough surface) [66]:

$$cos\theta_w = rcos\theta_y$$

The realization of this equation in the work of [24] indicates hydrophilic surface properties because the initial properties of titanium were improved by changing the surface texture (increase in roughness) and there was an increase in droplet diffusion [67].

Table 3. Wettability results on titanium and its alloys observed in the article.

Surface Property	Author, Year, and Reference	Short Conclusion
Wettability	Hao et al., 2005 [68]	Observation and study of the surface of laser-modified Ti6Al4V alloy showed an increase in the surface wettability which is beneficial for medical applications of titanium alloys. The increase in the contact angle after laser modification is a result, according to the authors, of an increase in the surface energy of the modified material and an increase in roughness parameters.
	Lawrence et al., 2006 [56]	Lawrence et al. demonstrated that laser treatment improves the surface wettability as a result of a change in the surface energy, an increase in the oxygen content, and an increase in the surface roughness. The cell studies carried out revealed an increase in bone cell adhesion and proliferation for Ti6Al4V titanium alloy samples subjected to laser modification, compared to a titanium alloy without modification.

Cunha, A. et al., 2013 [69]	Obtaining an anisotropic surface by modification is beneficial for controlling the surface wettability and this property is also indicated to improve stem cell adhesion.
May et al., 2015 [70]	The surface anisotropy of titanium alloy Ti6Al4V subjected to fiber-laser system modification was demonstrated. Wetting angles were smaller for the measurement performed perpendicularly for each laser operating frequency. The formation of contact anisotropy after laser modification was related to the frequency of the laser work, and increasing this parameter decreased the anisotropy.
Raimbault O. et al., 2016 [71]	The paper focused on the bioactivity of cells towards a femtosecond laser-modified surface but also examined the wettability of the Ti6Al4V titanium alloy, which was determined by measuring the contact angle. It was shown that the storage medium had a great influence on the change of the wettability characteristics of the modified samples. Samples stored in boiling water were slower to change their character to hydrophobic ones due to the slowing down of the passivation process, and the atmospheric environment accelerated these changes.
Rotella 2017 [72]	The authors used three methods for the surface modification of titanium alloy Ti6Al4V, one of them was a femtosecond laser treatment. The hydrophobic character of the laser-modified samples was observed, but at the same time, it was pointed out that this was not a disadvantage of such a surface because it gives, in a long-term context, a chance for a stronger bonding of the cells with the laser-modified implant.
Lu et al., 2018 [73]	A laser treatment at different laser fluence values was applied to pure titanium samples and then they were chemically treated. For each of the modification combinations, it was shown that the femtosecond laser modifications decreased the contact angle immediately after the laser treatment, while the contact angle increased after the modification. The possibility to obtain a stable structure with hydrophobic properties was pointed out in the paper as the most important advantage of such a modification.
Pires et al., 2017 [54]	The Nd: YAG laser treatment produced a superhydrophilic surface. The laser-modified surface consisted of more oxygen, which was one of the factors influencing the change in surface wettability. It was indicated that the use of this type of laser allows for the control of parameters important for bone cells.
Menci et al., 2019 [24]	In this study, a laser beam modification was performed using two different types of Nd: YAG laser and fiber laser, for different laser wavelengths. It was shown that a fiber laser processing ns 1064 nm produces the highest surface roughness with the greatest reduction in wetting angle. The paper also presents the possibility of using individual lasers with specific parameters to process specific implant components because of the roughness that can be achieved with them.
Murillo et al., 2019 [74]	It was observed that immediately after the modification of a Ti6Al4V titanium alloy with a UV ns laser and IR-fs pulsed lasers, the surface exhibited hydrophilic properties. In this study, the effect of the sample holding environment of titanium on material aging was investigated.
Shaikh et al., 2019 [75]	In this study, a decrease in the contact angle was observed for Ti6Al4V titanium alloy samples which underwent laser modification. It was also observed that the surface of the samples after laser treatment became hydrophilic immediately after the modification; however, during the storage of the material, the contact angle was tested again, and the results showed a change in the surface character toward a hydrophobic one. The authors suggested that this could be due to the oxidation of the modified film as well as contaminants deposited on the sample (the samples were stored in an atmospheric environment).
Dou et al., 2020 [76]	An increase in hydrophilicity with an increasing laser fluence was observed. The surface hydrophilicity was not stable, and the wettability of the surface changed to hydrophobic properties with time. The need for research on the stability of surface hydrophilicity was indicated.
Wang et al., 2021 [77]	A 355 mm UV laser modification of commercially pure titanium was carried out. In this study, the possibility of controlling the wettability by light and sample heating was demonstrated. The samples showed a superhydrophilic surface immediately after laser modification.
Mukherjee et al., 2021 [78]	In this paper, the laser modification of titanium alloy Ti6Al4V using a Yb-doped fiber laser was carried out. It was shown that the surface produced by the laser was anisotropic, which revealed that the contact angle for water was different for a parallel and perpendicular incidence of a drop on the surface. It was shown that in the direction parallel to the laser beam direction, the wetting of the surface was higher as a result of droplet propagation along the corrugation grooves.
Wang et al., 2021 [79]	A Ti6Al4V titanium alloy was modified with a UV laser at a wavelength of 355 nm. The results of the contact angle measurements were presented for three conditions: for the untreated sample (hydrophilic surface), the sample after laser treatment (superhydrophilic surface), and the sample

	modified with a laser and additionally subjected to a heat treatment (hydrophobic surface). For the same samples, an erosion test was performed and it was observed that the fastest erosion process occurred for the laser-modified samples and the slowest for those with a hydrophobic surface.
Singh et al., 2021 [80]	In this study, a CO2 laser modification was carried out on titanium Ti6Al4V alloys. After the modification, the values of the contact angle and surface energy were investigated. It was found that for the laser-modified surface, the contact angle was higher than for the unmodified samples, and the surface energy also increased. It was also found that a decrease in the surface energy resulted in a decrease in the affinity of the modified surface for bacteria, which is beneficial for the potential use of the material in implant production.
Li et al., 2022 [81]	Pure titanium samples were subjected to laser surface texturing. Wetting angle studies were carried out using distilled water and modified-simulated body fluid (m-SBF). For both fluids, the laser-modified surface showed an increased wettability. It was indicated that the drops on the structure with a higher roughness realized Wenzel's law, which explained the decrease in the contact angle. The wetting angle for the water was higher than for the m-SBF, which gave information that cells would grow better on such a substrate.

The literature identifies four terms for surface wettability: superhydrophilic, hydrophilic, hydrophobic, and superhydrophobic, concerning a drop of water falling on a surface Figure 3 [59].

The researchers, Lawrence et al. [56], Menci et al. [24] and Pries et al. [54], treated titanium alloys successively with an Nd: YAG and Yd: YAG laser, and based on contact angle studies, they showed that a laser modification increases the wettability of the sample surface successively for fluids such as human blood, human blood plasma, glycerol and 4-acetanol [56] and water [24]. A decrease in the wetting angle is also shown in Figure 4 for the modification made with the Nd: YAG laser [82]. Pries et al. [54] revealed that the contact angle measured after a laser treatment was 0°. Singh et al. [80] on the other hand, observed that the laser modification of a titanium alloy resulted in a decreased surface roughness, resulting in coatings with a lower wettability than unmodified samples.

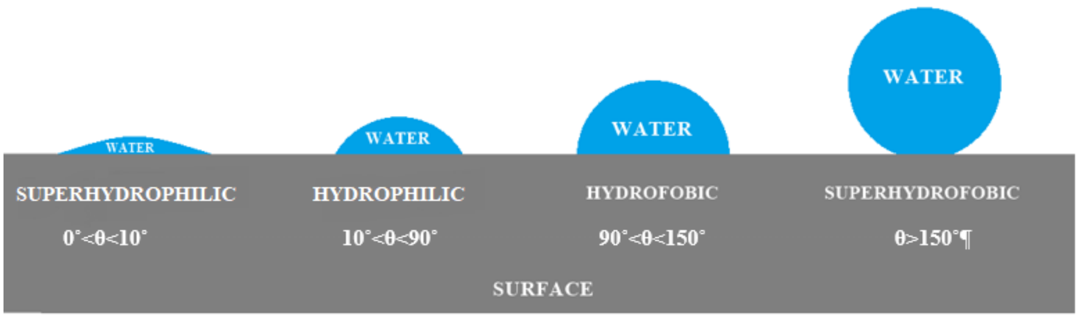

Figure 3. Categories of wettabilitybased on [59,66].

Researchers *Lawrence et al*. [56] *Menci et al.* [24] and *Pries et al* [54] treated titanium alloys successively with Nd: YAG and Yd: YAG laser, based on contact angle studies they showed that the laser modification increases the wettability of the sample surface successively for fluids such as human blood, human blood plasma, glycerol and 4-acetanol [56] and water [24]. The decrease in wetting angle is also shown in figure 4 for the modification made with the Nd:YAG laser [82]. *Pries et al.* [54] revealed that the contact angle measured after laser treatment is 0˚. *Singh et al.* [80] on the other hand, observed that laser modification of titanium alloy resulted in decreased surface roughness resulting in coatings with lower wettability than unmodified samples.

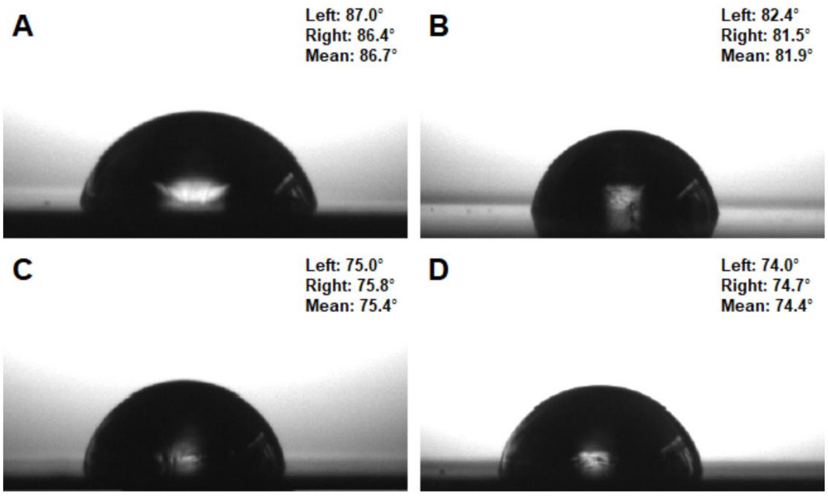

Figure 4. Wettability of material for (**A**) base material Ti13Nb13Zr, (**B**) laser modified sample 700 W, (**C**) laser modified sample 1000 W, and (**D**) laser modified sample 700 + 1000 W [82].

Conversely, in paper [76], a Ti: sapphire chirped-pulse regenerative amplification laser system with a central wavelength of 800 nm, was used to modify a Ti4Al6V alloy. Initially, the investigated surfaces were characterized by the hydrophilic nature of the modified surface. In the experiment, the contact angle measurements were performed cyclically for up to 155 days after the modification. The observations showed that the effect of the modified surfaces changed from hydrophilic to hydrophobic. Analogous results were also reported in the work of [69,74,75,81,83] for the contact angle for water and for Hank's balanced salt solution (HBSS) for titanium and titanium alloys.

In the research of [73], an alloy was laser-treated with a femtosecond laser, followed by an additional hydrothermal treatment and oxidation. The application of extra modifications did not change the previously established theory that states that with time, the contact angle of laser-modified surfaces increases. Raimbault et al. [71] pointed out that the increase in the contact angle after a certain time after a laser treatment increases due to the increasing passivation of the surface. Moreover, this paper shows that the environment of repository-modified samples is important due to the changing character of the sample wetting. Keeping the laser-modified TA6V samples in an air environment was associated with a faster change in the surface character from hydrophilic to hydrophobic, while an increase in the wetting angle for samples stored in boiling water was smaller. In the study of [72], it is depicted that the change in surface wettability from The decrease in wetting angle is hydrophilic to hydrophobic after a laser treatment does not adversely affect cell adhesion to the material. A better way to illustrate the bonding of a surface to a water droplet is to use the Cassie Baxter model, which takes into account the idea that the contact between a droplet and a surface is affected by air trapped in the irregularities [84]; therefore, an increase in the wetting angle is not uniquely associated with a weakening of the bond between the material and the cells. In addition, the bond is also affected by mechanical stress, which is related to the amount of cracking on the material surface [72].

The references of [62,74,82,83] indicate that laser-modified surfaces can exhibit anisotropic as well as isotropic properties depending on the laser operating parameters [69]. The anisotropy of a surface is more favorable due to its higher wettability than for isotropic surfaces and the contact angles for anisotropic surfaces will be different for parallel and perpendicular directions [70,78,85]. Surface modification resulting in an anisotropic surface is very important for the ability to control the wettability of materials [69], and in addition, due to the medical use of titanium and its alloys, the development of an anisotropic surface is beneficial because of improved osseointegration conditions [47]. It is indicated that the wettability character of laser-modified surfaces can be controlled and changed by external factors such as heat [77,79]. In the study of [77], the hydrophilic properties of a titanium alloy surface were observed immediately after laser modification. It was shown that it was possible to manipulate the character of the surface wettability by using the heating of the samples and UV radiation, which allowed the reversible transformation of the surface from hydrophilic to hydrophobic and the other way around.

4. Corrosion

Titanium and its alloys are characterized by a very high chemical activity. The Pourbaix diagram shows that titanium is a metal that passivates very quickly [86]. The natural, very good corrosion resistance of titanium and its alloys is indicated [87–91]. Additionally, the corrosion behavior is influenced by the presence of β-stabilizing alloying elements and their role in the stability and thickness of the passive layer formed [92]. An important direction of research is the study of the corrosion resistance of titanium bio-alloys [93,94], and to improve this property, it is necessary to limit as far as possible the release of metal ions into the body, since the possibility of adverse health effects due to the presence of, e.g., V or Al in the body has been identified [42,95,96].

It has been shown that titanium and its alloys are stable materials when exposed to environments that react with their surface, but the problem that arises in the root cause of this material is the development of fatigue corrosion, which occurs as a result of the loads on implants. For example, the stress-shielding effect that occurs in implants is due to the greater hardness of titanium than bone. The literature also states that cyclic loads induced by walking affect the corrosion resistance of titanium materials. Moreover, alloying additives in titanium alloys can have negative effects such as vanadium, aluminum, or chromium, whereas alloys with a density of, for example, niobium or tantalum lead to the formation of oxide layers which improve the root resistance of titanium alloys [97].

Laser modification allows the free manipulation of the surface roughness and wettability, which has a significant impact on the corrosion resistance of a material [98,99]. In 2012 [100], corrosion tests on pure titanium and titanium alloy with aluminum and vanadium were performed and based on the corrosion intensity (lA/cm^2), and it was observed that there was a decrease in the corrosion and corrosion-fatigue behavior of the studied materials after laser modification. It was indicated that the reason for the decrease in the corrosion resistance was the presence of residual stresses and small grain sizes in the modified surface, and the resulting microstructure changes differed in potential. The literature indicates that the grain size is affected by the modification of heat [101].

In contrast, the work of [102] cites results from 1984 (Picraux and Pope,) 2000 (Suzuki et al.), and 2002 (Yue et al.), which state that laser modification improves the corrosion resistance in, for example, Hank's solution. Travessa et al. [103] showed that laser modification caused significant metallurgical and chemical changes on the surface of an alloy, including the formation of oxides, which resulted in a significant improvement of the corrosion properties compared to metal not subjected to laser treatment. It was also observed, among other things, in the potentiodynamic polarization curves. Navarro [26] showed that a femtosecond laser modification caused changes in the surface of modified samples with different porosities, resulting in an increased impedance (Figure 5). Tests carried out by [103,104] indicated that a thicker oxide or nitride layer formed after laser modification on a material surface, improved the corrosion resistance of a titanium alloy. It was observed that the surface structure after the laser modification, when there were unevenly distributed phase components in it, affected the weakening of the corrosion resistance of the material. The corrosion resistance test carried out in a Ringer's solution Ti6Al4V titanium alloy [105,106], showed an increase in the corrosion resistance in acidic media. Whereas in the papers of [107,108], an increased corrosion resistance of laser-modified samples in Hank's solution and saline solution was shown.

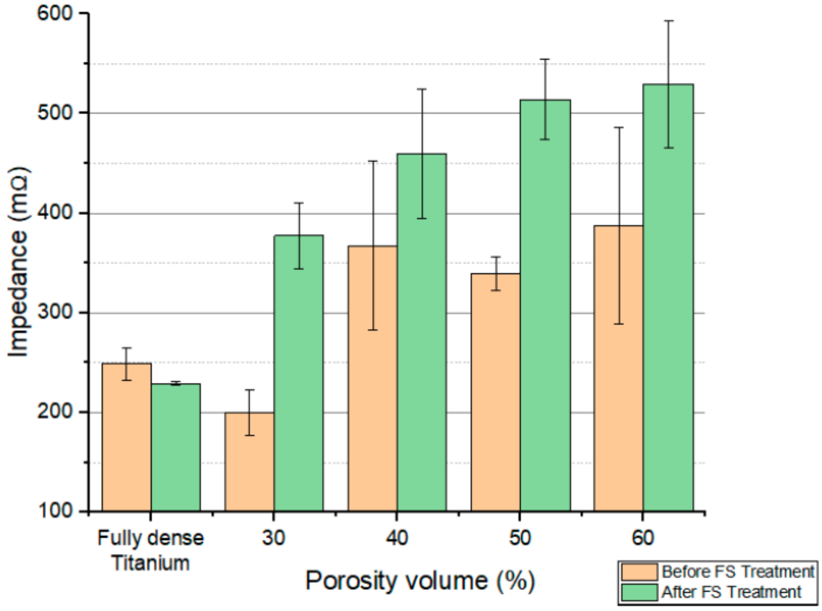

Figure 5. The change of impedance after laser modification for samples with different porosity volume [26].

Researchers in [78,109,110] investigated the effect of laser remelting on pitting and electrochemical corrosion resistance. An analysis of the polarization curves in the work [109] showed an increased resistance to pitting corrosion, which according to the authors was due to a microstructural modification caused by the rapid solidification that occurred during the laser remelting of the surface. Dhara et al. [78] have shown, based on obtained polarization curves, that as a result of the modification, the passive film formed a stable barrier against corrosion. In the paper of [106] it was pointed out that a higher electrochemical resistance was due to the reduction in the volume of the α and β phase, and the thickening of the surface texture. SEM and AFM studies carried out in [108] indicated that the laser modification formed a more reproducible and smoother topography, which increased the corrosion resistance of the material, and a stabilization of the passive layer on the titanium surface was observed, making it less susceptible to further growth [111]. Tests carried out on the chemical composition of the material showed an increase in the presence of nitrides, which acted as a barrier to the ingress of other molecules, and which was considered a condition that could improve the corrosion resistance of a material. An improvement in corrosion resistance by laser ablation was undertaken by [112] in their work, in which they removed the oxide layer, which gave their material a low corrosion resistance, and via the laser ablation, produced a corrosion-resistant oxide layer. This could be observed from an increase in the self-corrosion potential for different energy doses and a decrease in the self-corrosion current, which numerically reflected the corrosion rate of the material; therefore, indicating that the lower the surface corrosion rate the better the corrosion resistance.

5. Hardness

The hardness of titanium and its alloys is reported in the literature to be higher than the hardness of steel on the Vickers scale [113]. For example, titanium alloy Ti6Al4V has a hardness of HV higher (340 HV) than pure titanium (200 HV), which is related to the presence of alloying elements [114,115]. The surface modifications of these materials aim to improve the hardness and mechanical parameters to increase the residence time of an implant in the body [116]. The hardness of the materials used for implants is important because an increase in the material hardness is associated with an increase in the wear resistance [116]. The literature also indicates that the high hardness of a material can adversely affect the behavior of the biomaterial in the body [117]. Laser modification, on the other hand, allows a controlled change in the parameters. Hardness, for example, is widely discussed in the field of orthopedic implants, such as hip and knee implants, because of the need to control the shielding effect of the implant in the bone, and the importance of this parameter, as orthopedic implants are placed under a certain pressure in the body, meaning that the implant must counterbalance this pressure to perform its function properly [118].

A systematic review [119] and research by the authors [10,105,120–122] on the various techniques of the surface modification of titanium have observed an increase in the hardness of materials as a result of laser modification, which has its theoretical basis in [123], where it was indicated that by using a heat source it was possible to control changes in the hardness of materials. Table 4 shows the hardness values obtained for modified titanium alloys and pure titanium using different laser types and parameters. In Figure 6 it is also shown that laser modification improved the nano-hardness of Ti13Nb13Zr alloy samples after a laser modification by an Nd: YAG laser.

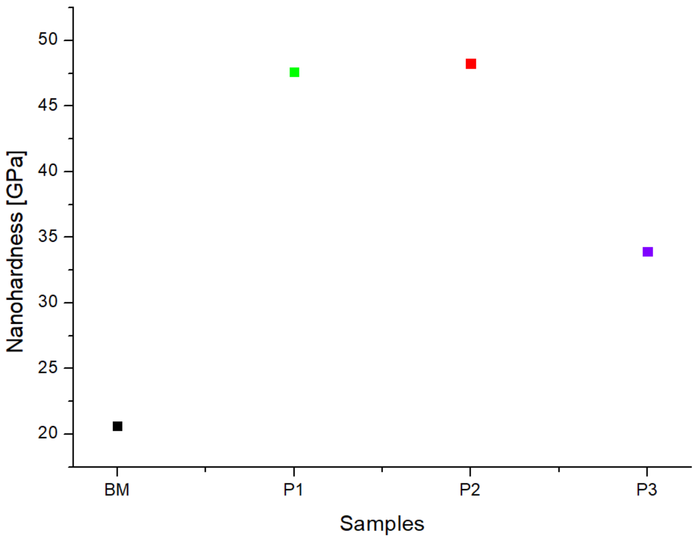

Figure 6. Nano-hardness of laser modified samples. BM: base material, P1: laser modified sample with 800 W and scan rate 60%, P2: laser modified sample with 800 W and scan rate 30%, P3: laser modified sample with 900 W and scan rate 60% [82].

In paper [105], the difference in the hardness value HV between the remelted material and the base material was about 300 HV. The study on the hardness of a titanium alloy was carried out by Khorram et al. [124] which indicated an increase in hardness of 36%. Additionally, Zhang et al. [125] indicated an increase in hardness after laser modification of 60%, while Ushakov et al. [126] determined that the possibility of increasing the Vickers hardness after a laser treatment ranged between 20% and 40%. Moreover, the increase in microhardness was accompanied by an increase in the fracture toughness. The laser modification of porous titanium in the research of [127] resulted in an increase in the hardness at the pore pillars, while an increase in the pore size in the titanium sample resulted in a decrease in the hardness. A significant effect of the pore size on the surface hardening potential by a laser modification was demonstrated.

The change in hardness of samples after laser remelting varies due to the phase transformations occurring during the cooling process [24,109,110]. The increase in material hardness is due to the transformation of the β-phase at high temperatures from about 900˚C to 1050 °C [128], into the α phase and the martensitic α phase, which is hard but very brittle [121,129–131], and the creation of the ω-phase [132,133]. After a laser-induced heat treatment, the formation of a martensitic α-phase was observed as a result of the transformation of the alpha-phase of titanium alloys initially into a beta-phase, and then during the rapid cooling of a material after laser treatment, a martensitic α-phase was formed [134]. Geng et al. [135] indicated that the hardness tests performed after a laser modification of the alloy showed that the measurement of this parameter performed in the β-phase, yielded lower values of hardness than in the α-phase. The results for the β-phase were characterized by large deviations for the elastic modulus due to the small thickness of the β-grains and the presence of α-grains. In studies [136,137] it has been shown that as a result of rapid cooling of a material at the surface after treatment, a martensitic phase with the addition of the β phase is formed, while deep into the material a decrease in the compactness of the martensitic phase is observed, and the α phase tends to become dominant. A comprehensive analysis of the phase transformation in a Ti-64 titanium alloy subjected to an Nd:YAG laser modification was carried out in [138]. The presence of a melted zone and a heat-affected zone after laser treatment were marked and they had different microstructural characteristics. The melted zone was characterized by the presence of martensitic plates throughout, while the heat-affected zone, which was far from the laser source, contained short-rod b particles, martensitic plates and untransformed bulk in its microstructure. It was shown that the change in hardness during laser treatment was influenced by the presence of martensitic plates in the melted zone and a reduction in the grain size. The formation of the martensitic phase limited the diffusion of alloying elements, which directly led to the hardening of the surface structure. The study of [138] presents the preliminary results of values for hardness, using a calculation method and a measurement method. For both methods, the hardness increased with respect to the material without a laser treatment. The hardness for the melted zone was higher than for the heated affected zone and the differences in the hardness values were due to the fact that the calculation method did not take into account the occurrence of coarse α grains in the heated zone, while it was also difficult to take into account the contribution of the individual phases of the material in the zones [138].

The authors of [125] further observed the formation of a large number of dislocations and mesh distortions on the surface of a sample, increasing the hardness of the material. In the melted zone, the formation of nanotwins was observed, which slowed down the dislocation movements, and this had an additional hardening effect on the material [138,139]. It was indicated that reducing the grain size increased the hardness of the material [109]; however, after laser treatment, the grain size of the material increased while the hardness increased, suggesting that the grain size does not significantly affect the hardness as much as the dislocations formed and the phase transformations of the material [140]. In the work of [141], it was indicated that an increase in the amount of oxygen due to a femtosecond laser treatment resulted in an increase in the hardness with a concomitant increase in the brittleness of the material. Applying laser texturing to the surface linearly and performing dimple patterns resulted in an increase in the nano-hardness from 2 GPa for the base material to 4 GPa and 6 GPa, respectively, as tested by nanoindentation. The hardness obtained for each test was dependent on the type of laser selected and the processing parameters chosen. In paper [142], a pulsed laser treatment was performed using two different laser power parameters, and the modified samples were divided into two regions. It was shown that the region of the sample modified with a higher laser power of 3.99 W had a higher hardness than the region modified with a laser power of 1.71 W. In addition, it was shown that for treatment with the lower laser power, no significant difference in the hardness were registered between the remelted layer and the native material. The research of [143] indicated that a laser modification with a low laser power did not increase the hardness of the material as much as in the case of a high laser power, for the reason that a lower power also means less heat and there is not as much formation of the martensitic alpha phase after remelting. A high laser power is directly related to the rapid cooling of the material and as a result the formation of the martensitic alpha phase. In the work of [144], the formation of a TiO_2 rutile and anatase phase was demonstrated, and it was indicated that the amount of oxygen molecules present in the structure depended on the laser modification method, namely, the type of laser and the parameters used. Pan et al. [145], as a result of their conducted research, indicated that the observed increase in the microhardness of the samples subjected to laser treatment was also because with an increase in the laser operating parameters there is an increase in the pressure. It was noted that an overly high value of the laser operating parameters was not able to effectively improve the microhardness of a surface [146], and this was because the yield strength of the titanium alloys had been exceeded [145]. The laser modification primarily increased the microhardness at the surface of the material, and the decrease in the hardness values was a gradient with an increasing test depth [145]. The change of the laser wavelength from 532 nm to 1064 nm showed a huge increase in the surface roughness which had a negative impact on the corrosion properties [147].

Table 4. Microhardness and hardness after laser treatment on titanium and its alloys.

Material	Microhardness and Hardness After Laser Treatment	Laser Parameters								References
		Type of Laser	: Energy/ Laser Power	Impact Time	Pulse Duration	Frequency	Scan Speed (Mm/S)	Laser Pulses	Environment	
Ti35Nb10Ta	3.8 GPa 3.3 GPa	Nd:YAG	1000 W 1500 W	- -	- -	- -	6.67 mm/s 10 mm/s	- -	Helium	[120]
	untreated material: 3.06 GPa	-	-	-	-	-	-		-	[148]
Ti30Nb4Sn	3.5 GPa 3.3 GPa	Nd: YAG	1000 W 1500 W	-	-	-	the authors 6.67 mm/s 10 mm/s	- -	Helium	[120]
	untreated material 2.44 GPa:									[149]
	4.9 GPa	Nd: YAG	50 mJ	-	-	10 Hz	-	-	Argon	[105]
	3, 4.01 for 150 μJ, 2.59 GPa for 240 μJ	femtosecond laser	10–240 μJ	-	290 fs	50 kHz	-	-	-	
Ti6Al4V	3.84 GPa 294 GPa	Nanosecond Laser Shock Peening (LSP	4 J	1 s 3 s	20 ns	1 H	-	-	-	[145]
Ti-5Al-2.5Sn	4.02 GPa	Nd:YAG	165 W	-	-	14 Hz	-	-	-	[124]
Ti6Al4V	2.45–3.43 GPa	-	-	-	-	-	-	500–18,000	-	[146]
Cp-Ti	untreated material: 1.08 GPa 2.59 GPa	Nd: YAG	100 W	-	5 ms	20 Hz	8 mm/s	-	-	[122]

6. Wear Resistance and Fatigue Behavior

An appropriate approach to improving wear resistance at present is to design alloys based on their chemical composition. In parallel, several technologies have been developed to prepare a modified layer with a high wear resistance [150]. The literature indicates that the direct effect on wear resistance is related to the hardness of a material [107,151]. One of the few disadvantages of titanium and its alloys is a low wear resistance [115]. For these materials, the need to improve this property is widely discussed [11,152] because the low wear resistance is a limitation of the various applications. Significant differences in the wear resistance of the various titanium alloys are indicated depending on the α, β, or $\alpha\beta$ type [150,153]. The literature points to a low wear resistance, especially in the case of titanium alloys β [92], for example, Ti-5Al-5Mo-5V-1Cr-1Fe [133], Ti–35Nb–7Zr–5Ta [154], and Ti10V2Fe3Al [155].

The literature reports that laser surface modification is a simple method to improve the wear resistance of a material [119,156–159]. In the research by Cheng et al. [133], despite an increased surface hardness after laser modification, no improvement in the wear resistance of the titanium alloy Ti5Al5Mo5V1Cr1Fe was observed.

The papers of [160,161] indicated that laser treatment in a nitrogen environment caused the formation of TiN, which significantly improved the surface hardness and wear resistance of the materials. The increased wear resistance was explained by a decrease in the coefficient of friction [160]. The research of [161] indicated that the relative wear resistance increased by 1.7 times compared to a material without a laser treatment. Moreover, the literature of [158] indicated that a TiN layer formed as a result of remelting in the presence of nitrogen, had a higher hardness and wear resistance than treated titanium alloys.

A study of the effect of laser processing on the wear resistance of pure titanium was carried out in [162], where laser processing was shown to reduce the weight loss of samples during a dry wear test. The study confirmed Archad's theory, that the wear rate is reversely proportional to the hardness [162,163]. The results of [162] for wear resistance indicated that the mass loss for a samples subjected to laser modification was much lower than for material without treatment, and that the wear indices for selected modified samples were practically constant, while for unmodified samples they increased significantly. The samples were subjected to a study of the change in the coefficient of friction during normal loading for increasing loads and the results in the cited work [162] indicated that the pure titanium samples without a modification showed a higher wear and material loss with an increasing normal load, while for modified samples a decrease in the wear was observed with increasing loads. In the work of [164], an increase in the wear resistance was observed in untreated material, while an increase in the load during the experiments lowered the wear resistance. The laser treatment created defects and when the load was applied, the structures were compressed, which increased the wear resistance because the material did not detach from the surface. It was shown that when the maximum temperature reached during the thermal cycle was higher than the melting temperature, a phase change to the martensitic phase occurred, and the fatigue strength and wear resistance of the material were improved; thus, this procedure is also used in the hardening of steels and cast irons [137].

The study results of Zeng et al. [165] also indicated that a laser treatment improved the wear resistance of a material, that the diagram of the dependence of a material loss volume on the wear time for both a non-laser treated and treated material was linear, except for modified samples where a small mass loss was observed, and that it was 37 times lower than the wear of the raw material. The ion release tests carried out showed that the increased wear resistance determined the reduced release of vanadium, which is a toxic element.

In the study of [166], as a result of laser modification, the formation of TiC was observed and it was indicated that the presence of this composite improved the hardness and wear resistance. It was shown that short laser processing times were more advantageous because the melted layer was more homogeneous. Moreover, increasing the laser processing time increased the hardness and surface roughness but the TiC structure was more uneven and hard TiC particles acted as an abrasive tool. The low speed of the laser beam on the material, causing the formation of deeper melts, also had a beneficial effect on increasing the wear resistance of the material.

In paper [167], an XRD study of a Ti834 alloy subjected to modification was carried out, where the fatigue strength (high cycle fatigue) was tested. It was shown that for modified samples there was an increase in the tested strength, which was justified by the formation of compressive stresses after laser shock peening. Jia et al. [168] confirmed that in this type of laser processing, compressive stresses are induced in the sample and increase with an increasing impact time. A 1998 study [169] showed that laser modification combined with previous coating applications allowed for a reduction in the adhesive and abrasive wear.

The researchers of [170,171] compared the treatment of titanium by ion implantation and laser nitriding. It was shown that the use of a CO_2 laser in a nitrogen environment allowed a reduction in the friction between the tested surfaces, with a concomitant decrease in the fatigue strength [171]. Another study [170] evaluated the fretting fatigue behavior of a titanium alloy. It was observed that due to the formation of a heterogeneous, brittle surface after machining during fretting, the surface of the titanium alloy was unable to accept the loads set during fretting. Current literature [172–174] also shows that the use of laser modification is associated with decreasing the fatigue strength in titanium alloys. It is indicated that the fatigue strength is reduced by up to 30% compared to the very good fatigue strength of titanium alloys [172,175]. Additionally, it was indicated that with the increase in surface roughness after laser treatment, the cracks occurring on the surface generate a reduction in the fatigue strength. The resulting surface damage was identified as crack initiation sites [174]. The untreated material had crack initiation sites at the edges of the material, while in the case of the laser-treated material, the initiation site was in the center of the material [173].

7. Conclusions

The literature review focused on the effects of laser modification without material gain on titanium and its alloys. The presented work provides a comprehensive knowledge base on the effects of a fiber laser, Nd: YAG, Yd: YAG laser, and femtosecond laser and the shock peening method on selected properties of the titanium materials used in the medical industry. The paper discusses such properties as the roughness, wettability, resistance to corrosion, wear, and fatigue, as well as the effect of laser modification on material hardness.

1. The first section focused on the surface roughness and wettability, allowing us to assess the impact of laser modification with different types of lasers, which led to the conclusion that the use of this type of modification increases the surface roughness and that it varies depending on the operating parameters of the lasers.
2. The wettability of a surface is a topic that is widely discussed due to the fact that laser modification affects the change in the nature of the surface. Notably, a large impact on the hydrophilicity or hydrophobicity of a surface is the timing of the test in this direction, as well as the environment in which the samples are stored, but depending on the application of the material, there are different requirements, which does not indicate a more advantageous character.
3. Collected publications in the field of corrosion resistance research determine that the action of a laser beam on titanium materials improves the corrosion resistance, which is important because this reduces the release of dangerous elements from the implants.
4. Laser modification alters the micro- and nano-hardness for each type of laser. It is indicated that laser modification allows the process to be carried out in such a way that the hardness obtained after the change is close to that of bone.
5. The effect of laser modification on material wear was presented based on a collection of literature from a wide time range, which allowed the presentation of further opportunities to discuss the selection of optimal laser operating parameters, such as the laser operating power, laser beam density, and pulse duration.
6. In addition, the aspect of wear resistance was discussed, where it was shown that the use of laser modification improves this material property.
7. The presented review of the current literature on the subject provides a theoretical basis for studying the effects of laser processing on titanium and its biostops and for conducting targeted processing in the area where modification is needed to improve implants.
8. The presented review of the current literature related to the effects of laser modification on selected properties of titanium materials and provides a theoretical basis for the researchers' research.
9. The review indicates the need to deepen the research related to the wettability of the surface of titanium materials used in biomedicine, due to the fact that there is no clear

indication of which character of the surface is more favorable, and it is necessary to identify the areas of application of a hydrophobic and hydrophilic surface obtained by modification. In addition, it is important to focus on studies related to the durability of materials against wear and fatigue and corrosion because these two properties directly affect the length of stay of an implant in the body.

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References

1. Bandyopadhyay, A.; Sahasrabudhe, H.; Bose, S. *Laser Surface Modification of Metallic Biomaterials*; Elsevier Ltd.: Amsterdam, The Netherlands, 2016; ISBN 9780081009420.
2. Ardila-Rodríguez, L.A.; Menezes, B.R.C.; Pereira, L.A.; Takahashi, R.J.; Oliveira, A.C.; Travessa, D.N. Surface Modification of Aluminum Alloys with Carbon Nanotubes by Laser Surface Melting. *Surf. Coatings Technol.* **2019**, *377*, 1–11. https://doi.org/10.1016/j.surfcoat.2019.124930.
3. Landowski, M. Influence of parameters of laser beam welding on structure of 2205 duplex stainless steel. *Adv. Mater. Sci.* **2019**, *19*, 1–11. https://doi.org/10.2478/adms-2019-0002.
4. Mao, B.; Siddaiah, A.; Liao, Y.; Menezes, P.L. Laser Surface Texturing and Related Techniques for Enhancing Tribological Performance of Engineering Materials: A Review. *J. Manuf. Process.* **2020**, *53*, 153–173. https://doi.org/10.1016/j.jmapro.2020.02.009.
5. Daskalova, A.; Angelova, L.; Carvalho, A.; Trifonov, A.; Nathala, C.; Monteiro, F.; Buchvarov, I. Effect of Surface Modification by Femtosecond Laser on Zirconia Based Ceramics for Screening of Cell-Surface Interaction. *Appl. Surf. Sci.* **2020**, *513*, 145914. https://doi.org/10.1016/j.apsusc.2020.145914.
6. Yang, L.; Ding, Y.; Cheng, B.; He, J.; Wang, G.; Wang, Y. Investigations on Femtosecond Laser Modified Micro-Textured Surface with Anti-Friction Property on Bearing Steel GCr15. *Appl. Surf. Sci.* **2018**, *434*, 831–842. https://doi.org/10.1016/j.apsusc.2017.10.234.
7. Temmler, A.; Walochnik, M.A.; Willenborg, E.; Wissenbach, K. Surface Structuring by Remelting of Titanium Alloy Ti6Al4V. *J. Laser Appl.* **2015**, *27*, 1–7. https://doi.org/10.2351/1.4906387.
8. Laketić, S.; Rakin, M.; Momčilović, M.; Ciganović, J.; Veljović, Đ.; Cvijović-Alagić, I. Surface Modifications of Biometallic Commercially Pure Ti and Ti-13Nb-13Zr Alloy by Picosecond Nd:YAG Laser. *Int. J. Miner. Metall. Mater.* **2021**, *28*, 285–295. https://doi.org/10.1007/s12613-020-2061-9.
9. Jażdewska, M.; Kwidzińska, D.B.; Seyda, W.; Fydrych, D.; Zieleiński, A. Mechanical Properties and Residual Stress Measurements of Grade IV Titanium and Ti-6Al-4V and Ti-13Nb-13Zr Titanium Alloys after Laser Treatment. *Materials* **2021**, *14*, 6316.
10. Majkowska-Marzec, B.; Sypniewska, J. Microstructure and Mechanical Properties of Laser Surface-Treated Ti13Nb13Zr Alloy with MWCNTs Coatings. *Adv. Mater. Sci.* **2021**, *21*, 5–18. https://doi.org/10.2478/adms-2021-0021.
11. Zieliński, A.; Jażdżewska, M.; Łubiński, J.; Serbiński, W. Effects of Laser Remelting at Cryogenic Conditions on Microstructure and Wear Resistance of the Ti6Al4V Alloy Applied in Medicine. *Trans Tech Publ.* **2012**, *183*, 215–224. https://doi.org/10.4028/www.scientific.net/SSP.183.215.
12. Lisiecki, A.; Klimpel, A. Diode Laser Surface Modification of Ti6Al4V Alloy to Improve Erosion Wear Resistance. *Arch. Mater. Sci. Eng.* **2008**, *32*, 5–12.
13. Amaya-Vazquez, M.R.; Sánchez-Amaya, J.M.; Boukha, Z.; Botana, F.J. Microstructure, Microhardness and Corrosion Resistance of Remelted TiG2 and Ti6Al4V by a High Power Diode Laser. *Corros. Sci.* **2012**, *56*, 36–48. https://doi.org/10.1016/j.corsci.2011.11.006.
14. Lisiecki, A. Hybrid Laser Deposition of Composite WC-Ni Layers with Forced Local Cryogenic Cooling. *Materials* **2021**, *14*, 4312.
15. Lv, F.; Liang, H.; Xie, D.; Mao, Y.; Wang, C.; Shen, L.; Tian, Z. On the Role of Laser in Situ Re-Melting into Pore Elimination of Ti–6Al–4V Components Fabricated by Selective Laser Melting. *J. Alloys Compd.* **2021**, *854*, 156866. https://doi.org/10.1016/j.jallcom.2020.156866.
16. Temmler, A.; Willenborg, E.; Wissenbach, K. Designing Surfaces by Laser Remelting Designing Surfaces by Laser Remelting. In Proceedings of the ICOMM 2012—International Conference on Micromanufacturing, Evanston, Illinois, 12–14 March 2014. https://doi.org/10.13140/2.1.1555.8409.

17. Szkodo, M.; Bień, A.; Stanisławska, A. Laser Beam as a Precision Tool to Increase Fatigue Resistance in an Eyelet of Undercarriage Drag Strut. *Int. J. Precis. Eng. Manuf. - Green Technol.* **2022**, *9*, 175–190. https://doi.org/10.1007/s40684-020-00296-2.
18. Ukar, E.; Lamikiz, A.; Martínez, S.; Arrizubieta, I. Laser Texturing with Conventional Fiber Laser. *Procedia Eng.* **2015**, *132*, 663–670. https://doi.org/10.1016/j.proeng.2015.12.545.
19. Aragaw, E.M.; Gärtner, E.; Schubert, A.; Stief, P.; Dantan, J.; Etienne, A.; Siadat, A. ScienceDirect ScienceDirect Combined Laser Hardening and Laser Surface Texturing Forming Tool 1 . 2379 Combined Laser Hardening and Laser Surface Texturing Existing Products for an Assembly Oriented Product Family Identification Methodology to Analyze The. *Procedia CIRP* **2020**, *94*, 914–918. https://doi.org/10.1016/j.procir.2020.09.072.
20. Balasubramanian, S.; Muthukumaran, V.; Sathyabalan, P. A Study of the Effect of Process Parameters of Laser Hardening in Carbon Steels. *Int. J. Civ. Eng. Technol.* **2017**, *8*, 201–207.
21. Poulon-Quintin, A.; Watanabe, I.; Watanabe, E.; Bertrand, C. Microstructure and Mechanical Properties of Surface Treated Cast Titanium with Nd:YAG Laser. *Dent. Mater.* **2012**, *28*, 945–951. https://doi.org/10.1016/j.dental.2012.04.008.
22. Xu, Y.; Liu, W.; Zhang, G.; Li, Z.; Hu, H.; Wang, C.; Zeng, X.; Zhao, S.; Zhang, Y.; Ren, T. Friction Stability and Cellular Behaviors on Laser Textured Ti–6Al–4V Alloy Implants with Bioinspired Micro-Overlapping Structures. *J. Mech. Behav. Biomed. Mater.* **2020**, *109*, 1–14. https://doi.org/10.1016/j.jmbbm.2020.103823.
23. Braga, F.J.C.; Marques, R.F.C.; de Filho, E.A.; Guastaldi, A.C. Surface Modification of Ti Dental Implants by Nd:YVO 4 Laser Irradiation. *Appl. Surf. Sci.* **2007**, *253*, 9203–9208. https://doi.org/10.1016/j.apsusc.2007.05.048.
24. Menci, G.; Gökhan, A.; Waugh, D.G.; Lawrence, J.; Previtali, B. Applied Surface Science Laser Surface Texturing of β-Ti Alloy for Orthopaedics : Effect of Different Wavelengths and Pulse Durations. *Appl. Surf. Sci.* **2019**, *489*, 175–186. https://doi.org/10.1016/j.apsusc.2019.05.111.
25. Yadi, M.; Esfahani, H.; Sheikhi, M.; Mohammadi, M. CaTiO3/α-TCP Coatings on CP-Ti Prepared via Electrospinning and Pulsed Laser Treatment for in-Vitro Bone Tissue Engineering. *Surf. Coatings Technol.* **2020**, *401*, 126256. https://doi.org/10.1016/j.surfcoat.2020.126256.
26. Navarro, P.; Olmo, A.; Giner, M.; Rodríguez-Albelo, M.; Rodríguez, Á.; Torres, Y. Electrical Impedance of Surface Modified Porous Titanium Implants with Femtosecond Laser. *Materials* **2022**, *15*, 461. https://doi.org/10.3390/ma15020461.
27. Jażdżewska, M.; Majkowska-Marzec, B. Hydroxyapatite Deposition on the Laser Modified Ti13Nb13Zr Alloy. *Adv. Mater. Sci.* **2018**, *17*, 5–13. https://doi.org/10.1515/adms-2017-0017.
28. Dywel, P.; Szczesny, R.; Domanowski, P.; Skowronski, L. Structural and Micromechanical Properties of Nd:YAG Laser Marking Stainless Steel (AISI 304 and AISI 316). *Materials* **2020**, *13*, 2168. https://doi.org/10.3390/ma13092168.
29. Fujii, H.; Takahashi, K.; Yamashita, Y. Application of Titanium and Its Alloys for Automobile Parts. *Nippon Steel Tech. Rep.* **2003**, *02003*, 70–75. https://doi.org/10.1051/matecconf/202032102003.
30. Assari, A.H.; Eghbali, B. Solid State Diffusion Bonding Characteristics at the Interfaces of Ti and Al Layers. *J. Alloys Compd.* **2019**, *773*, 50–58. https://doi.org/10.1016/j.jallcom.2018.09.253.
31. Tabie, V.M.; Li, C.; Saifu, W.; Li, J.; Xu, X. Mechanical Properties of near Alpha Titanium Alloys for High-Temperature Applications - a Review. *Aircr. Eng. Aerosp. Technol.* **2020**, *92*, 521–540. https://doi.org/10.1108/AEAT-04-2019-0086.
32. Gomez-Gallegos, A.; Mandal, P.; Gonzalez, D.; Zuelli, N.; Blackwell, P. Studies on Titanium Alloys for Aerospace Application. *Defect Diffus. Forum* **2018**, *385 DDF*, 419–423. https://doi.org/10.4028/www.scientific.net/DDF.385.419.
33. Elshazli, A.M.; Elshaer, R.N.; Hussein, A.H.A.; Al-Sayed, S.R. Erratum: Elshazli et Al. Laser Surface Modification of TC21 (α/β) Titanium Alloy Using a Direct Energy Deposition (DED) Process. *Micromachines* **2021**, *12*, 739. https://doi.org/10.3390/mi12091078.
34. Khorasani, A.M.; Goldberg, M.; Doeven, E.H.; Littlefair, G. Titanium in Biomedical Applications—Properties and Fabrication : A Review. *J. Biomater. Tissue Eng.* **2015**, *5*, 593–619. https://doi.org/10.1166/jbt.2015.1361.
35. Laska, A. Parameters of the Electrophoretic Deposition Process and Its Influence on the Morphology of Hydroxyapatite Coatings. Review. *Inżynieria Mater.* **2020**, *1*, 20–25. https://doi.org/10.15199/28.2020.1.3.
36. Watanabe, I.; McBride, M.; Newton, P.; Kurtz, K.S. Laser Surface Treatment to Improve Mechanical Properties of Cast Titanium. *Dent. Mater.* **2009**, *25*, 629–633. https://doi.org/10.1016/j.dental.2008.11.006.
37. Shah, F.A.; Johansson, M.L.; Omar, O.; Simonsson, H.; Palmquist, A.; Thomsen, P. Laser-Modified Surface Enhances Osseointegration and Biomechanical Anchorage of Commercially Pure Titanium Implants for Bone-Anchored Hearing Systems. *PLoS One* **2016**, *11*, e0157504. https://doi.org/10.1371/journal.pone.0157504.
38. Koizumi, H.; Takeuchi, Y.; Imai, H.; Kawai, T.; Yoneyama, T. Application of Titanium and Titanium Alloys to Fixed Dental Prostheses. *J. Prosthodont. Res.* **2019**, *63*, 266–270. https://doi.org/10.1016/j.jpor.2019.04.011.
39. Wierzchoń, T. Modification of Titanium and Its Alloys Implants by Low Temperature Surface Plasma Treatments for Cardiovascular Applications. *Inżynieria Mater.* **2018**, *1*, 4–13. https://doi.org/10.15199/28.2018.4.1.
40. Manjaiah, M.; Laubscher, R.F. A Review of the Surface Modifications of Titanium Alloys for Biomedical Applications. *Mater. Tehnol.* **2017**, *51*, 181–193. https://doi.org/10.17222/mit.2015.348.
41. Yamaguchi, T.; Hagino, H. Formation of Titanium Carbide Layer by Laser Alloying with a Light-Transmitting Resin. *Opt. Lasers Eng.* **2017**, *88*, 13–19. https://doi.org/10.1016/j.optlaseng.2016.07.007.
42. Piotrowska, K.; Madej, M.; Ozimina, D. assessment of tribological properties of ti13nb13zr titanium alloy used in medicine. *Tribologia* **2019**, *285*, 97–106. https://doi.org/10.5604/01.3001.0013.5440.

43. Chen, Q.; Thouas, G.A. Metallic Implant Biomaterials. *Mater. Sci. Eng. R Reports* **2015**, *87*, 1–57. https://doi.org/10.1016/j.mser.2014.10.001.
44. Tian, Y.S.; Chen, C.Z.; Wang, D.Y.; Lei, T.Q. Laser surface modification of titanium alloys—A review. *Surf. Eng. Light Alloy. Alum. Magnes. Titan. Alloy.* **2010**, *12*, 398–443. https://doi.org/10.1533/9781845699451.2.398.
45. Sirdeshmukh, N.; Dongre, G. Laser Micro & Nano Surface Texturing for Enhancing Osseointegration and Antimicrobial Effect of Biomaterials: A Review. *Mater. Today Proc.* **2021**, *44*, 2348–2355. https://doi.org/10.1016/j.matpr.2020.12.433.
46. Kurella, A.; Dahotre, N.B. Review Paper: Surface Modification for Bioimplants: The Role of Laser Surface Engineering. *J. Biomater. Appl*. **2005**, *20*, 1–25. ISBN 0885328205.
47. Xue, X.; Ma, C.; An, H.; Li, Y.; Guan, Y. Corrosion Resistance and Cytocompatibility of Ti-20Zr-10Nb-4Ta Alloy Surface Modified by a Focused Fiber Laser. *Sci. China Mater.* **2018**, *61*, 516–524. https://doi.org/10.1007/s40843-017-9239-3.
48. Simões, I.G.; dos Reis, A.C.; da Costa Valente, M.L. Analysis of the Influence of Surface Treatment by High-Power Laser Irradiation on the Surface Properties of Titanium Dental Implants: A Systematic Review. *J. Prosthet. Dent.* **2021**, 1–8. https://doi.org/10.1016/j.prosdent.2021.07.026.
49. Abdal-hay, A.; Staples, R.; Alhazaa, A.; Fournier, B.; Al-Gawati, M.; Lee, R.S.; Ivanovski, S. Fabrication of Micropores on Titanium Implants Using Femtosecond Laser Technology: Perpendicular Attachment of Connective Tissues as a Pilot Study. *Opt. Laser Technol.* **2022**, *148*, 107624. https://doi.org/10.1016/j.optlastec.2021.107624.
50. Korovessis, P.G.; Deligianni, D.D. Role of Surface Roughness of Titanium Versus Hydroxyapatite on Human Bone Marrow Cells Response. *J. Spinal Disord. Tech.* **2002**, *15*, 175–183.
51. Elias, C.N.; Lima, J.H.C.; Valiev, R.; Meyers, M.A. Biomedical Applications of Titanium and Its Alloys Biological Materials Science 46-49. *Biol. Mater. Sci.* **2008**, 30, 46–49.
52. Achneck, H.E.; Jamiolkowski, R.M.; Jantzen, A.E.; Haseltine, J.M.; Lane, W.O.; Huang, J.K.; Galinat, L.J.; Serpe, M.J.; Lin, F.H.; Li, M.; et al. The Biocompatibility of Titanium Cardiovascular Devices Seeded with Autologous Blood-Derived Endothelial Progenitor Cells. EPC-Seeded Antithrombotic Ti Implants. *Biomaterials* **2011**, *32*, 10–18. https://doi.org/10.1016/j.biomaterials.2010.08.073.
53. Ramesh, S.; Karunamoorthy, L.; Palanikumar, K. Surface Roughness Analysis in Machining of Titanium Alloy. *Mater. Manuf. Process.* **2008**, *23*, 174–181. https://doi.org/10.1080/10426910701774700.
54. Pires, L.C.; Guastaldi, F.P.S.; Nogueira, A.V.B.; Oliveira, N.T.C.; Guastaldi, A.C.; Cirelli, J.A. Physicochemical, Morphological, and Biological Analyses of Ti-15Mo Alloy Surface Modified by Laser Beam Irradiation. *Lasers Med. Sci.* **2019**, *34*, 537–546. https://doi.org/10.1007/s10103-018-2626-2.
55. Telegin, S.V.; Lyasnikova, A. V.; Dudareva, O.A.; Grishina, I.P.; Markelova, O.A.; Lyasnikov, V.N. Laser Modification of the Surface of Titanium: Technology, Properties, and Prospects of Application. *J. Surf. Investig.* **2019**, *13*, 228–231. https://doi.org/10.1134/S1027451019020174.
56. Lawrence, J.; Hao, L.; Chew, H.R. On the Correlation between Nd:YAG Laser-Induced Wettability Characteristics Modification and Osteoblast Cell Bioactivity on a Titanium Alloy. *Surf. Coatings Technol.* **2006**, *200*, 5581–5589. https://doi.org/10.1016/j.surfcoat.2005.07.107.
57. Rafiee, K.; Naffakh-Moosavy, H.; Tamjid, E. The Effect of Laser Frequency on Roughness, Microstructure, Cell Viability and Attachment of Ti6Al4V Alloy. *Mater. Sci. Eng. C* **2020**, *109*, 110637. https://doi.org/10.1016/j.msec.2020.110637.
58. Györgyey, Á.; Ungvári, K.; Kecskeméti, G.; Kopniczky, J.; Hopp, B.; Oszkó, A.; Pelsöczi, I.; Rakonczay, Z.; Nagy, K.; Turzó, K. Attachment and Proliferation of Human Osteoblast-like Cells (MG-63) on Laser-Ablated Titanium Implant Material. *Mater. Sci. Eng. C* **2013**, *33*, 4251–4259. https://doi.org/10.1016/j.msec.2013.06.020.
59. Samanta, A.; Wang, Q.; Singh, G.; Shaw, S.K.; Toor, F.; Ratner, A.; Ding, H. Nanosecond Pulsed Laser Processing Turns Engineering Metal Alloys Antireflective and Superwicking. *J. Manuf. Process.* **2020**, *54*, 28–37. https://doi.org/10.1016/j.jmapro.2020.02.029.
60. Laketić, S.; Rakin, M.; Momčilović, M.; Ciganović, J.; Veljović; Cvijović-Alagić, I. Influence of Laser Irradiation Parameters on the Ultrafine-Grained Ti[Sbnd]45Nb Alloy Surface Characteristics. *Surf. Coatings Technol.* **2021**, *418*, 127255. https://doi.org/10.1016/j.surfcoat.2021.127255.
61. Liu, Q.; Liu, Y.; Li, X.; Dong, G. Pulse Laser-Induced Cell-like Texture on Surface of Titanium Alloy for Tribological Properties Improvement. *Wear* **2021**, *477*, 203784. https://doi.org/10.1016/j.wear.2021.203784.
62. Zaifuddin, A.Q.; Zulhilmi, F.; Aiman, M.H.; Quazi, M.M.; Ishak, M. Enhancement of Laser Heating Process by Laser Surface Modification on Titanium Alloy. *J. Mech. Eng. Sci.* **2021**, *15*, 8310–8318. https://doi.org/10.15282/jmes.15.3.2021.09.0653.
63. Schnell, U.G.; Duenow, H.S. Effect of Laser Pulse Overlap and Scanning Line Overlap on Femtosecond Laser-Structured Ti6Al4V Surfaces. *Materials* **2020**, *13*, 969.
64. Eghbali, N.; Naffakh-Moosavy, H.; Sadeghi Mohammadi, S.; Naderi-Manesh, H. The Influence of Laser Frequency and Groove Distance on Cell Adhesion, Cell Viability, and Antibacterial Characteristics of Ti-6Al-4V Dental Implants Treated by Modern Fiber Engraving Laser. *Dent. Mater.* **2021**, *37*, 547–558. https://doi.org/10.1016/j.dental.2020.12.007.
65. György, E.; Pérez del Pino, A.; Serra, P.; Morenza, J.L. Influence of the Ambient Gas in Laser Structuring of the Titanium Surface. *Surf. Coatings Technol.* **2004**, *187*, 245–249. https://doi.org/10.1016/j.surfcoat.2004.03.015.
66. El Mogahzy, Y.E. Finishing Processes for Fibrous Assemblies in Textile Product Design. *Eng. Text.* **2009**, 300–326. https://doi.org/10.1533/9781845695415.2.300.

67. Zheng, Q.; Mao, L.; Shi, Y.; Fu, W.; Hu, Y. Biocompatibility of Ti-6Al-4V Titanium Alloy Implants with Laser Microgrooved Surfaces. *Mater. Technol.* **2020**, 1–10. https://doi.org/10.1080/10667857.2020.1816011.
68. Hao, L.; Lawrence, J.; Li, L. Manipulation of the Osteoblast Response to a Ti-6Al-4V Titanium Alloy Using a High Power Diode Laser. *Appl. Surf. Sci.* **2005**, *247*, 602–606. https://doi.org/10.1016/j.apsusc.2005.01.165.
69. Cunha, A.; Serro, A.P.; Oliveira, V.; Almeida, A.; Vilar, R.; Durrieu, M.C. Wetting Behaviour of Femtosecond Laser Textured Ti-6Al-4V Surfaces. *Appl. Surf. Sci.* **2013**, *265*, 688–696. https://doi.org/10.1016/j.apsusc.2012.11.085.
70. May, A.; Agarwal, N.; Lee, J.; Lambert, M.; Akkan, C.K.; Nothdurft, F.P.; Aktas, O.C. Laser Induced Anisotropic Wetting on Ti-6Al-4V Surfaces. *Mater. Lett.* **2015**, *138*, 21–24. https://doi.org/10.1016/j.matlet.2014.09.092.
71. Raimbault, O.; Benayoun, S.; Anselme, K.; Mauclair, C.; Bourgade, T.; Kietzig, A.M.; Girard-Lauriault, P.L.; Valette, S.; Donnet, C. The Effects of Femtosecond Laser-Textured Ti-6Al-4V on Wettability and Cell Response. *Mater. Sci. Eng. C* **2016**, *69*, 311–320. https://doi.org/10.1016/j.msec.2016.06.072.
72. Rotella, G.; Orazi, L.; Alfano, M.; Candamano, S.; Gnilitskyi, I. Innovative High-Speed Femtosecond Laser Nano-Patterning for Improved Adhesive Bonding of Ti6Al4V Titanium Alloy. *CIRP J. Manuf. Sci. Technol.* **2017**, *18*, 101–106. https://doi.org/10.1016/j.cirpj.2016.10.003.
73. Lu, J.; Huang, T.; Liu, Z.; Zhang, X.; Xiao, R. Long-Term Wettability of Titanium Surfaces by Combined Femtosecond Laser Micro/Nano Structuring and Chemical Treatments. *Appl. Surf. Sci.* **2018**, *459*, 257–262. https://doi.org/10.1016/j.apsusc.2018.08.004.
74. Huerta-Murillo, D.; García-Girón, A.; Romano, J.M.; Cardoso, J.T.; Cordovilla, F.; Walker, M.; Dimov, S.S.; Ocaña, J.L. Wettability Modification of Laser-Fabricated Hierarchical Surface Structures in Ti-6Al-4V Titanium Alloy. *Appl. Surf. Sci.* **2019**, *463*, 838–846. https://doi.org/10.1016/j.apsusc.2018.09.012.
75. Shaikh, S.; Kedia, S.; Singh, D.; Subramanian, M.; Sinha, S. Surface Texturing of Ti6Al4V Alloy Using Femtosecond Laser for Superior Antibacterial Performance. *J. Laser Appl.* **2019**, *31*, 5081106. https://doi.org/10.2351/1.5081106.
76. Dou, H.Q.; Liu, H.; Xu, S.; Chen, Y.; Miao, X.; Lü, H.; Jiang, X. Influence of Laser Fluences and Scan Speeds on the Morphologies and Wetting Properties of Titanium Alloy. *Optik (Stuttg).* **2020**, *224*, 165443. https://doi.org/10.1016/j.ijleo.2020.165443.
77. Wang, Q.; Wang, H.; Zhu, Z.; Xiang, N.; Wang, Z.; Sun, G. Switchable Wettability Control of Titanium via Facile Nanosecond Laser-Based Surface Texturing. *Surf. Interfaces* **2021**, *24*, 101122. https://doi.org/10.1016/j.surfin.2021.101122.
78. Mukherjee, S.; Dhara, S.; Saha, P. Enhanced Corrosion, Tribocorrosion Resistance and Controllable Osteogenic Potential of Stem Cells on Micro-Rippled Ti6Al4V Surfaces Produced by Pulsed Laser Remelting. *J. Manuf. Process.* **2021**, *65*, 119–133. https://doi.org/10.1016/j.jmapro.2021.03.023.
79. Wang, Z.; Song, J.; Wang, T.; Wang, H. Laser Texturing for Superwetting Titanium Alloy and Investigation of Its Erosion Resistance. *Coatings* **2021**, *11*, 1547.
80. Singh, I.; George, S.M.; Tiwari, A.; Ramkumar, J.; Balani, K. Influence of Laser Surface Texturing on the Wettability and Antibacterial Properties of Metallic, Ceramic, and Polymeric Surfaces. *J. Mater. Res.* **2021**, *36*, 3985–3999. https://doi.org/10.1557/s43578-021-00273-8.
81. Li, H.; Wang, X.; Zhang, J.; Wang, B.; Breisch, M.; Hartmaier, A.; Rostotskyi, I.; Voznyy, V.; Liu, Y. Experimental Investigation of Laser Surface Texturing and Related Biocompatibility of Pure Titanium. *Int. J. Adv. Manuf. Technol.* **2022**. https://doi.org/10.1007/s00170-022-08710-6.
82. Tęczar, P.; Majkowska-Marzec, B. The influence of laser alloying of ti13nb13zr on surface topography and properties. *Adv. Mater. Sci.* **2019**, *19*, 45–55. https://doi.org/10.2478/adms-2019-0004.
83. Ta, D.V.; Dunn, A.; Wasley, T.J.; Kay, R.W.; Stringer, J.; Smith, P.J.; Connaughton, C.; Shephard, J.D. Nanosecond Laser Textured Superhydrophobic Metallic Surfaces and Their Chemical Sensing Applications. *Appl. Surf. Sci.* **2015**, *357*, 248–254. https://doi.org/10.1016/j.apsusc.2015.09.027.
84. Liu, K.; Yao, X.; Jiang, L. Recent Developments in Bio-Inspired Special Wettability. *Chem. Soc. Rev.* **2010**, *39*, 3240–3255. https://doi.org/10.1039/b917112f.
85. Mukherjee, S.; Dhara, S.; Saha, P. Laser Surface Remelting of Ti and Its Alloys for Improving Surface Biocompatibility of Orthopaedic Implants. *Mater. Technol.* **2018**, *33*, 106–118. https://doi.org/10.1080/10667857.2017.1390931.
86. De Oliveira, V.M.C.A.; Aguiar, C.; Vazquez, A.M.; Robin, A.L.M.; Barboza, M.J.R. Corrosion Behavior Analysis of Plasma-Assited PVD Coated Ti-6Al-4V Alloy in 2 M NaOH Solution. *Mater. Res.* **2017**, *20*, 436–444. https://doi.org/10.1590/1980-5373-MR-2015-0737.
87. Dinu, M.; Franchi, S.; Pruna, V.; Cotrut, C.M.; Secchi, V.; Santi, M.; Titorencu, I.; Battocchio, C.; Iucci, G.; Vladescu, A. *Ti-Nb-Zr System and Its Surface Biofunctionalization for Biomedical Applications*; Elsevier Inc.: Amsterdam, The Netherlands, 2018; ISBN 9780128124567.
88. Supernak-Marczewska, M.; Ossowska, A.; Strąkowska, P.; Zieliński, A. Nanotubular Oxide Layers and Hydroxyapatite Coatings on Porous Titanium Alloy Ti13Nb13Zr. *Adv. Mater. Sci.* **2018**, *18*, 17–23. https://doi.org/10.1515/adms-2017-0046.
89. Ferdinandov, N.V.; Gospodinov, D.D.; Ilieva, M.D.; Radev, R.H. Structure and Pitting Corrosion of Ti-6al-4v Alloy and Ti-6al-4v Welds. *ICAMS Proc. Int. Conf. Adv. Mater. Syst.* **2018**, 325–330. https://doi.org/10.24264/icams-2018.VI.7.
90. Gu, K.X.; Wang, K.K.; Zheng, J.P.; Chen, L.B.; Wang, J.J. Electrochemical Behavior of Ti–6Al–4V Alloy in Hank’s Solution Subjected to Deep Cryogenic Treatment. *Rare Met.* **2018**. https://doi.org/10.1007/s12598-018-1163-2.

91. Wang, Y.; Tayyebi, M.; Assari, A. Fracture Toughness, Wear, and Microstructure Properties of Aluminum/Titanium/Steel Multi-Laminated Composites Produced by Cross-Accumulative Roll-Bonding Process. *Arch. Civ. Mech. Eng.* **2022**, *22*, 1–14. https://doi.org/10.1007/s43452-021-00355-8.
92. Çaha, I.; Alves, A.C.; Rocha, L.A.; Toptan, F. A Review on Bio-Functionalization of β-Ti Alloys. *J. Bio- Tribo-Corrosion* **2020**, *6*, 1–31. https://doi.org/10.1007/s40735-020-00432-0.
93. Dias Corpa Tardelli, J.; Bolfarini, C.; Cândido dos Reis, A. Comparative Analysis of Corrosion Resistance between Beta Titanium and Ti-6Al-4V Alloys: A Systematic Review. *J. Trace Elem. Med. Biol.* **2020**, *62*, 126618. https://doi.org/10.1016/j.jtemb.2020.126618.
94. Pawłowski, Ł.; Bartmański, M.; Mielewczyk-Gryń, A.; Zieliński, A. Effects of Surface Pretreatment of Titanium Substrates on Properties of Electrophoretically Deposited Biopolymer Chitosan/Eudragit e 100 Coatings. *Coatings* **2021**, *11*, 1–19. https://doi.org/10.3390/coatings11091120.
95. Surma, M.K.; Adach, M.; Dębowska, P.; Turlej, P.S. Projekt i analiza obliczeniowa implantU. *Aktual. Probl. Biomech.* **2019**, 111–122.
96. Bartmański, M.; Pawłowski, Ł.; Zieliński, A.; Mielewczyk-Gryń, A.; Strugała, G.; Cieślik, B. Electrophoretic Deposition and Characteristics of Chitosan-Nanosilver Composite Coatings on a Nanotubular TiO2 Layer. *Coatings* **2020**, *10*, 1–16. https://doi.org/10.3390/coatings10030245.
97. Manivasagam, G.; Dhinasekaran, D.; Rajamanickam, A. Biomedical Implants : Corrosion and Its Prevention -A Review Biomedical Implants : Corrosion and Its Prevention—A Review. **2010**, *2*. https://doi.org/10.2174/1877610801002010040.
98. Boinovich, L.B.; Gnedenkov, S.V.; Alpysbaeva, D.A.; Egorkin, V.S.; Emelyanenko, A.M.; Sinebryukhov, S.L.; Zaretskaya, A.K. Corrosion Resistance of Composite Coatings on Low-Carbon Steel Containing Hydrophobic and Superhydrophobic Layers in Combination with Oxide Sublayers. *Corros. Sci.* **2012**, *55*, 238–245. https://doi.org/10.1016/j.corsci.2011.10.023.
99. Stepanovska, J.; Matejka, R.; Rosina, J.; Bacakova, L.; Kolarova, H. Treatments for Enhancing the Biocompatibility of Titanium Implants. *Biomed. Pap.* **2020**, *164*, 23–33. https://doi.org/10.5507/bp.2019.062.
100. Gil, F.J.; Delgado, L.; Espinar, E.; Llamas, J.M. Corrosion and Corrosion-Fatigue Behavior of Cp-Ti and Ti-6Al-4V Laser-Marked Biomaterials. *J. Mater. Sci. Mater. Med.* **2012**, *23*, 885–890. https://doi.org/10.1007/s10856-012-4572-z.
101. Tayyebi, M.; Adhami, M.; Karimi, A.; Davood Rahmatabadi; Alizadeh, M.; Hashemi, R. Effects of Strain Accumulation and Annealing on Interfacial Microstructure and Grain Structure (Mg and Al3Mg2 Layers) of Al/Cu/Mg Multilayered Composite Fabricated by ARB Process. *J. Mater. Res. Technol.* **2021**, *14*, 392–406. https://doi.org/10.1016/j.jmrt.2021.06.032.
102. Mohammed, M.T.; Khan, Z.A.; Siddiquee, A.N. Surface Modifications of Titanium Materials for Developing Corrosion Behavior in Human Body Environment: A Review. *Procedia Mater. Sci.* **2014**, *6*, 1610–1618. https://doi.org/10.1016/j.mspro.2014.07.144.
103. Nagle Travessa, D.; Vilas Boas Guedes, G.; Capella de Oliveira, A.; Regina Cardoso, K.; Roche, V.; Moreira Jorge, A. The Effect of Surface Laser Texturing on the Corrosion Performance of the Biocompatible β-Ti12Mo6Zr2Fe Alloy. *Surf. Coatings Technol.* **2021**, *405*. https://doi.org/10.1016/j.surfcoat.2020.126628.
104. Zeng, C.; Wen, H.; Hemmasian Ettefagh, A.; Zhang, B.; Gao, J.; Haghshenas, A.; Raush, J.R.; Guo, S.M. Reoxidation Process and Corrosion Behavior of TA15 Alloy by Laser Ablation. *Surf. Coatings Technol.* **2020**, *385*, 125397. https://doi.org/10.1016/j.surfcoat.2020.125397.
105. Al-Sayed, S.R.; Abdelfatah, A. Corrosion Behavior of a Laser Surface-Treated Alpha–Beta 6/4 Titanium Alloy. *Metallogr. Microstruct. Anal.* **2020**, *9*, 553–560. https://doi.org/10.1007/s13632-020-00667-w.
106. Singh, R.; Tiwari, S.K.; Mishra, S.K.; Dahotre, N.B. Electrochemical and Mechanical Behavior of Laser Processed Ti-6Al-4V Surface in Ringer's Physiological Solution. *J. Mater. Sci. Mater. Med.* **2011**, *22*, 1787–1796. https://doi.org/10.1007/s10856-011-4362-z.
107. Kumari, R.; Scharnweber, T.; Pfleging, W.; Besser, H.; Majumdar, J.D. Laser Surface Textured Titanium Alloy (Ti-6Al-4V) - Part II - Studies on Bio-Compatibility. *Appl. Surf. Sci.* **2015**, *357*, 750–758. https://doi.org/10.1016/j.apsusc.2015.08.255.
108. Kuczyńska-Zemła, D.; Sotniczuk, A.; Pisarek, M.; Chlanda, A.; Garbacz, H. Corrosion Behavior of Titanium Modified by Direct Laser Interference Lithography. *Surf. Coatings Technol.* **2021**, *418*, 127219. https://doi.org/10.1016/j.surfcoat.2021.127219.
109. Sun, Z.; Annergren, I.; Pan, D.; Mai, T.A. Effect of Laser Surface Remelting on the Corrosion Behavior of Commercially Pure Titanium Sheet. *Mater. Sci. Eng. A* **2003**, *345*, 293–300. https://doi.org/10.1016/S0921-5093(02)00477-X.
110. Xu, Y.; Li, Z.; Zhang, G.; Wang, G.; Zeng, Z.; Wang, C.; Wang, C.; Zhao, S.; Zhang, Y.; Ren, T. Electrochemical Corrosion and Anisotropic Tribological Properties of Bioinspired Hierarchical Morphologies on Ti-6Al-4V Fabricated by Laser Texturing. *Tribol. Int.* **2019**, *134*, 352–364. https://doi.org/10.1016/j.triboint.2019.01.040.
111. Ali, N.; Mustapa, M.S.; Ghazali, M.I.; Sujitno, T.; Ridha, M. Fatigue Life Prediction of Commercially Pure Titanium after Nitrogen Ion Implantation. *Int. J. Automot. Mech. Eng.* **2013**, *7*, 1005–1013. https://doi.org/10.15282/ijame.7.2012.16.0081.
112. Liu, B.W.; Mi, G.Y.; Wang, C.M. Reoxidation Process and Corrosion Behavior of TA15 Alloy by Laser Ablation. *Rare Met.* **2021**, *40*, 865–876. https://doi.org/10.1007/s12598-020-01553-8.
113. Baxter, J.W.; Bumby, J.R. Fuzzy Control of a Mobile Robotic Vehicle. *Proc. Inst. Mech. Eng. Part I J. Syst. Control. Eng.* **1995**, *209*. https://doi.org/10.1243/PIME_PROC_1995_209_369_02.
114. Da Rocha, S.S.; Adabo, G.L.; Henriques, G.E.P.; Nóbilo, M.A.D.A. Vickers Hardness of Cast Commercially Pure Titanium and Ti-6Al-4V Alloy Submitted to Heat Treatments. *Braz. Dent. J.* **2006**, *17*, 126–129. https://doi.org/10.1590/s0103-64402006000200008.
115. Sharma, A.; Waddell, J.N.; Li, K.C.; A Sharma, L.; Prior, D.J.; Duncan, W.J. Is Titanium–Zirconium Alloy a Better Alternative to Pure Titanium for Oral Implant? Composition, Mechanical Properties, and Microstructure Analysis. *Saudi Dent. J.* **2021**, *33*, 546–553. https://doi.org/10.1016/j.sdentj.2020.08.009.

116. Sharan, J.; Lale, S.V.; Koul, V.; Mishra, M.; Kharbanda, O.P. An Overview of Surface Modifications of Titanium and Its Alloys for Biomedical Applications. *Trends Biomater. Artif. Organs* **2015**, *29*, 176–187.
117. Davis, R.; Singh, A.; Jackson, M.J.; Coelho, R.T.; Prakash, D.; Charalambous, C.P.; Ahmed, W.; da Silva, L.R.R.; Lawrence, A.A. *A Comprehensive Review on Metallic Implant Biomaterials and Their Subtractive Manufacturing*; Springer: London, UK, 2022; Volume 120; ISBN 0123456789.
118. Pan, J.; Prabakaran, S.; Rajan, M. In-Vivo Assessment of Minerals Substituted Hydroxyapatite / Poly Sorbitol Sebacate Glutamate (PSSG) Composite Coating on Titanium Metal Implant for Orthopedic Implantation. *Biomed. Pharmacother.* **2019**, *119*, 109404. https://doi.org/10.1016/j.biopha.2019.109404.
119. Zhang, L.C.; Chen, L.Y.; Wang, L. Surface Modification of Titanium and Titanium Alloys: Technologies, Developments, and Future Interests. *Adv. Eng. Mater.* **2020**, *22*, 1–37. https://doi.org/10.1002/adem.201901258.
120. Rossi, M.C.; Amado, J.M.; Tobar, M.J.; Vicente, A.; Yañez, A.; Amigó, V. Effect of Alloying Elements on Laser Surface Modification of Powder Metallurgy to Improve Surface Mechanical Properties of Beta Titanium Alloys for Biomedical Application. *J. Mater. Res. Technol.* **2021**, *14*, 1222–1234. https://doi.org/10.1016/j.jmrt.2021.07.037.
121. Conradi, M.; Kocijan, A.; Klobčar, D.; Godec, M. Influence of Laser Texturing on Microstructure, Surface and Corrosion Properties of Ti-6al-4v. *Metals* **2020**, *10*, 1504. https://doi.org/10.3390/met10111504.
122. Chai, L.; Wu, H.; Zheng, Z.; Guan, H.; Pan, H.; Guo, N.; Song, B. Microstructural Characterization and Hardness Variation of Pure Ti Surface-Treated by Pulsed Laser. *J. Alloys Compd.* **2018**, *741*, 116–122. https://doi.org/10.1016/j.jallcom.2018.01.113.
123. Pushp, P.; Dasharath, S.M.; Arati, C. Classification and Applications of Titanium and Its Alloys. *Mater. Today Proc.* **2022**. https://doi.org/10.1016/j.matpr.2022.01.008.
124. Khorram, A.; Davoodi Jamaloei, A.; Jafari, A. Surface Transformation Hardening of Ti-5Al-2.5Sn Alloy by Pulsed Nd:YAG Laser: An Experimental Study. *Int. J. Adv. Manuf. Technol.* **2019**, *100*, 3085–3099. https://doi.org/10.1007/s00170-018-2900-2.
125. Zhang, T.; Fan, Q.; Ma, X.; Wang, W.; Wang, K.; Shen, P.; Yang, J.; Wang, L. Effect of Laser Remelting on Microstructural Evolution and Mechanical Properties of Ti-35Nb-2Ta-3Zr Alloy. *Mater. Lett.* **2019**, *253*, 310–313. https://doi.org/10.1016/j.matlet.2019.06.105.
126. Ushakov, I.; Simonov, Y. Alterations in the Microhardness of a Titanium Alloy Affected to a Series of Nanosecond Laser Pulses. *MATEC Web Conf.* **2019**, *298*, 00051. https://doi.org/10.1051/matecconf/201929800051.
127. Trueba, P.; Giner, M.; Rodríguez, Á.; Beltrán, A.M.; Amado, J.M.; Montoya-García, M.J.; Rodríguez-Albelo, L.M.; Torres, Y. Tribo-Mechanical and Cellular Behavior of Superficially Modified Porous Titanium Samples Using Femtosecond Laser. *Surf. Coatings Technol.* **2021**, *422*, 127555. https://doi.org/10.1016/j.surfcoat.2021.127555.
128. Omoniyi, P.O.; Akinlabi, E.T.; Mahamood, R.M. Heat Treatments of Ti6Al4V Alloys for Industrial Applications: An Overview. *IOP Conf. Ser. Mater. Sci. Eng.* **2021**, *1107*, 012094. https://doi.org/10.1088/1757-899x/1107/1/012094.
129. Xu, Y.F.; Yi, D.Q.; Liu, H.Q.; Wang, B.; Yang, F.L. Age-Hardening Behavior, Microstructural Evolution and Grain Growth Kinetics of Isothermal ω Phase of Ti-Nb-Ta-Zr-Fe Alloy for Biomedical Applications. *Mater. Sci. Eng. A* **2011**, *529*, 326–334. https://doi.org/10.1016/j.msea.2011.09.035.
130. Zafari, A.; Barati, M.R.; Xia, K. Controlling Martensitic Decomposition during Selective Laser Melting to Achieve Best Ductility in High Strength Ti-6Al-4V. *Mater. Sci. Eng. A* **2019**, *744*, 445–455. https://doi.org/10.1016/j.msea.2018.12.047.
131. El-Hadad, S.; Nady, M.; Khalifa, W.; Shash, A. Influence of Heat Treatment Conditions on the Mechanical Properties of Ti–6Al–4V Alloy. *Can. Metall. Q.* **2018**, *57*, 186–193. https://doi.org/10.1080/00084433.2017.1412557.
132. Yao, Y.; Li, X.; Wang, Y.Y.; Zhao, W.; Li, G.; Liu, R.P. Microstructural Evolution and Mechanical Properties of Ti-Zr Beta Titanium Alloy after Laser Surface Remelting. *J. Alloys Compd.* **2014**, *583*, 43–47. https://doi.org/10.1016/j.jallcom.2013.08.160.
133. He, B.; Cheng, X.; Li, J.; Tian, X.J.; Wang, H.M. Effect of Laser Surface Remelting and Low Temperature Aging Treatments on Microstructures and Surface Properties of Ti-55511 Alloy. *Surf. Coatings Technol.* **2017**, *316*, 104–112. https://doi.org/10.1016/j.surfcoat.2016.11.097.
134. Guo, B.; Jonas, J.J. Dynamic Transformation during the High Temperature Deformation of Titanium Alloys. *J. Alloys Compd.* **2021**, *884*, 161179. https://doi.org/10.1016/j.jallcom.2021.161179.
135. Geng, Y.; McCarthy, É.; Brabazon, D.; Harrison, N. Ti6Al4V Functionally Graded Material via High Power and High Speed Laser Surface Modification. *Surf. Coatings Technol.* **2020**, *398*, 126085. https://doi.org/10.1016/j.surfcoat.2020.126085.
136. Moura, C.G.; Carvalho, O.; Gonçalves, L.M.V.; Cerqueira, M.F.; Nascimento, R.; Silva, F. Laser Surface Texturing of Ti-6Al-4V by Nanosecond Laser: Surface Characterization, Ti-Oxide Layer Analysis and Its Electrical Insulation Performance. *Mater. Sci. Eng. C* **2019**, *104*, 109901. https://doi.org/10.1016/j.msec.2019.109901.
137. Vilar, R.; Almeida, A. *Laser Surface Treatment of Biomedical Alloys*; Elsevier Ltd.: Amsterdam, The Netherlands, 2016; ISBN 9780081009420.
138. Dai, J.; Wang, T.; Chai, L.; Hu, X.; Zhang, L.; Guo, N. Characterization and Correlation of Microstructure and Hardness of Ti–6Al–4V Sheet Surface-Treated by Pulsed Laser. *J. Alloys Compd.* **2020**, *826*, 154243. https://doi.org/10.1016/j.jallcom.2020.154243.
139. Chai, L.; Chen, K.; Zhi, Y.; Murty, K.L.; Chen, L.Y.; Yang, Z. Nanotwins Induced by Pulsed Laser and Their Hardening Effect in a Zr Alloy. *J. Alloys Compd.* **2018**, *748*, 163–170. https://doi.org/10.1016/j.jallcom.2018.03.126.
140. Zhang, T.; Fan, Q.; Ma, X.; Wang, W.; Wang, K.; Shen, P.; Yang, J. Microstructure and Mechanical Properties of Ti-35Nb-2Ta-3Zr Alloy by Laser Quenching. *Front. Mater.* **2019**, *6*, 318. https://doi.org/10.3389/fmats.2019.00318.
141. Pfleging, W.; Kumari, R.; Besser, H.; Scharnweber, T.; Majumdar, J.D. Laser Surface Textured Titanium Alloy (Ti-6Al-4V): Part 1 - Surface Characterization. *Appl. Surf. Sci.* **2015**, *355*, 104–111. https://doi.org/10.1016/j.apsusc.2015.06.175.

142. Chen, S.; Usta, A.D.; Eriten, M. Microstructure and Wear Resistance of Ti6Al4V Surfaces Processed by Pulsed Laser. *Surf. Coatings Technol.* **2017**, *315*, 220–231. https://doi.org/10.1016/j.surfcoat.2017.02.031.
143. Chauhan, A.S.; Jha, J.S.; Telrandhe, S.; Srinivas, V.; Gokhale, A.A.; Mishra, S.K. Laser Surface Treatment of α-β Titanium Alloy to Develop a β -Rich Phase with Very High Hardness. *J. Mater. Process. Technol.* **2021**, *288*, 116873. https://doi.org/10.1016/j.jmatprotec.2020.116873.
144. Kashyap, V.; Ramkumar, P. Improved Oxygen Diffusion and Overall Surface Characteristics Using Combined Laser Surface Texturing and Heat Treatment Process of Ti6Al4V. *Surf. Coatings Technol.* **2022**, *429*, 127976. https://doi.org/10.1016/j.surfcoat.2021.127976.
145. Pan, X.; HE, W.; Cai, Z.; Wang, X.; Liu, P.; Luo, S.; Zhou, L. Investigations on Femtosecond Laser-Induced Surface Modification and Periodic Micropatterning with Anti-Friction Properties on Ti6Al4V Titanium Alloy. *Chinese J. Aeronaut.* **2022**, *35*, 521–537. https://doi.org/10.1016/j.cja.2021.01.003.
146. Rajesh, P.; Muraleedharan, C.V.; Komath, M.; Varma, H. Laser Surface Modification of Titanium Substrate for Pulsed Laser Deposition of Highly Adherent Hydroxyapatite. *J. Mater. Sci. Mater. Med.* **2011**, *22*, 1671–1679. https://doi.org/10.1007/s10856-011-4342-3.
147. Ranjith Kumar, G.; Rajyalakshmi, G. Role of Nano Second Laser Wavelength Embedded Recast Layer and Residual Stress on Electrochemical Corrosion of Titanium Alloy. *Mater. Res. Express* **2019**, *6*, 086583. https://doi.org/10.1088/2053-1591/ab1fb2.
148. Utomo, E.P.; Herbirowo, S.; Puspasari, V.; Thaha, Y.N. Characteristics and Corrosion Behavior of Ti–30nb–5sn Alloys in Histidine Solution with Various Nacl Concentrations. *Int. J. Corros. Scale Inhib.* **2021**, *10*, 592–601. https://doi.org/10.17675/2305-6894-2021-10-2-7.
149. Arrazola, P.J.; Garay, A.; Iriarte, L.M.; Armendia, M.; Marya, S.; Le Maître, F. Machinability of Titanium Alloys (Ti6Al4V and Ti555.3). *J. Mater. Process. Technol.* **2009**, *209*, 2223–2230. https://doi.org/10.1016/j.jmatprotec.2008.06.020.
150. Shao, L.; Du, Y.; Dai, K.; Wu, H.; Wang, Q.; Liu, J.; Tang, Y. β-Ti Alloys for Orthopedic and Dental Applications: A Review of Progress on Improvement of Properties through Surface Modificatio. *Coatings* **2021**, *11*, 1446.
151. He, D.; Zheng, S.; Pu, J.; Zhang, G.; Hu, L. Improving Tribological Properties of Titanium Alloys by Combining Laser Surface Texturing and Diamond-like Carbon Film. *Tribol. Int.* **2015**, *82*, 20–27. https://doi.org/10.1016/j.triboint.2014.09.017.
152. Kaur, M.; Singh, K. Review on Titanium and Titanium Based Alloys as Biomaterials for Orthopaedic Applications. *Mater. Sci. Eng. C* **2019**, *102*, 844–862. https://doi.org/10.1016/j.msec.2019.04.064.
153. Faria, A.C.L.; Rodrigues, R.C.S.; Claro, A.P.R.A.; de Mattos, M.G.C.; Ribeiro, R.F. Wear Resistance of Experimental Titanium Alloys for Dental Applications. *J. Mech. Behav. Biomed. Mater.* **2011**, *4*, 1873–1879. https://doi.org/10.1016/j.jmbbm.2011.06.004.
154. Vishnu, J.; Sankar, M.; Rack, H.J.; Rao, N.; Singh, A.K.; Manivasagam, G. Effect of Phase Transformations during Aging on Tensile Strength and Ductility of Metastable Beta Titanium Alloy Ti–35Nb–7Zr–5Ta-0.35O for Orthopedic Applications. *Mater. Sci. Eng. A* **2020**, *779*. https://doi.org/10.1016/j.msea.2020.139127.
155. Qiu, C.; Liu, Q.; Ding, R. Significant Enhancement in Yield Strength for a Metastable Beta Titanium Alloy by Selective Laser Melting. *Mater. Sci. Eng. A* **2021**, *816*, 141291. https://doi.org/10.1016/j.msea.2021.141291.
156. Makuch, N.; Kulka, M.; Dziarski, P.; Przestacki, D. Laser Surface Alloying of Commercially Pure Titanium with Boron and Carbon. *Opt. Lasers Eng.* **2014**, *57*, 64–81. https://doi.org/10.1016/j.optlaseng.2014.01.019.
157. Hatakeyama, M.; Masahashi, N.; Michiyama, Y.; Inoue, H.; Hanada, S. Wear Resistance of Surface-Modified TiNbSn Alloy. *J. Mater. Sci.* **2021**, *56*, 14333–14347. https://doi.org/10.1007/s10853-021-06213-5.
158. Zhang, L.C.; Chen, L.Y. A Review on Biomedical Titanium Alloys: Recent Progress and Prospect. *Adv. Eng. Mater.* **2019**, *21*, 1–29. https://doi.org/10.1002/adem.201801215.
159. Salguero, J.; Del Sol, I.; Vazquez-Martinez, J.M.; Schertzer, M.J.; Iglesias, P. Effect of Laser Parameters on the Tribological Behavior of Ti6Al4V Titanium Microtextures under Lubricated Conditions. *Wear* **2019**, *426–427*, 1272–1279. https://doi.org/10.1016/j.wear.2018.12.029.
160. Wang, H.; Nett, R.; Gurevich, E.L. The Effect of Laser Nitriding on Surface Characteristics and Wear Resistance of NiTi Alloy with Low Power Fiber Laser. *Appl. Sci.* **2021**, *11*, 515.
161. Jiang, P.; He, X.L.; Li, X.X.; Yu, L.G.; Wang, H.M. Wear Resistance of a Laser Surface Alloyed Ti-6Al-4V Alloy. *Surf. Coatings Technol.* **2000**, *130*, 24–28. https://doi.org/10.1016/S0257-8972(00)00680-0.
162. Bahiraei, M.; Mazaheri, Y.; Sheikhi, M.; Heidarpour, A. Mechanism of TiC Formation in Laser Surface Treatment of the Commercial Pure Titanium Pre-Coated by Carbon Using PVD Process. *J. Alloys Compd.* **2020**, *834*, 155080. https://doi.org/10.1016/j.jallcom.2020.155080.
163. Tabrizi, A.T.; Aghajani, H.; Saghafian, H.; Laleh, F.F. Correction of Archard Equation for Wear Behavior of Modified Pure Titanium. *Tribol. Int.* **2021**, *155*, 106772. https://doi.org/10.1016/j.triboint.2020.106772.
164. Veiko, V.P.; Odintsova, G.V.; Gazizova, M.Y.; Karlagina, Y.Y.; Manokhin, S.S.; Yatsuk, R.M.; Vasilkov, S.D.; Kolobov, Y.R. The Influence of Laser Micro- and Nanostructuring on the Wear Resistance of Grade-2 Titanium Surface. *Laser Phys.* **2018**, *28*. https://doi.org/10.1088/1555-6611/aac05a.
165. Zeng, X.; Wang, W.; Yamaguchi, T.; Nishio, K. Characteristics of Surface Modified Ti-6Al-4V Alloy by a Series of YAG Laser Irradiation. *Opt. Laser Technol.* **2018**, *98*, 106–112. https://doi.org/10.1016/j.optlastec.2017.07.048.
166. Mohazzab, B.F.; Jaleh, B.; Fattah-alhosseini, A.; Mahmoudi, F.; Momeni, A. Laser Surface Treatment of Pure Titanium: Microstructural Analysis, Wear Properties, and Corrosion Behavior of Titanium Carbide Coatings in Hank's Physiological Solution. *Surf. Interfaces* **2020**, *20*, 100597. https://doi.org/10.1016/j.surfin.2020.100597.

167. Jia, W.; Hong, Q.; Zhao, H.; Li, L.; Han, D. Effect of Laser Shock Peening on the Mechanical Properties of a Near-α Titanium Alloy. *Mater. Sci. Eng. A* **2014**, *606*, 354–359. https://doi.org/10.1016/j.msea.2014.03.108.
168. Jia, W.; Zan, Y.; Mao, C.; Li, S.; Zhou, W.; Li, Q.; Zhang, S.; Ji, V. Microstructure Evolution and Mechanical Properties of a Lamellar Near-α Titanium Alloy Treated by Laser Shock Peening. *Vacuum* **2021**, *184*, 109906. https://doi.org/10.1016/j.vacuum.2020.109906.
169. Langlade, C.; Vannes, A.B.; Krafft, J.M.; Martin, J.R. Surface Modification and Tribological Behaviour of Titanium and Titanium Alloys after YAG-Laser Treatments. *Surf. Coatings Technol.* **1998**, *100–101*, 383–387. https://doi.org/10.1016/S0257-8972(97)00653-1.
170. Vadiraj, A.; Kamaraj, M. Fretting Fatigue Behavior of Surface Modified Biomedical Titanium Alloys. *Trans. Indian Inst. Met.* **2010**, *63*, 217–223. https://doi.org/10.1007/s12666-010-0030-0.
171. Vadiraj, A.; Kamaraj, M.; Kamachi Mudali, U.; Nath, A.K. Effect of Surface Modified Layers on Fretting Fatigue Damage of Biomedical Titanium Alloys. *Mater. Sci. Technol.* **2006**, *22*, 1119–1125. https://doi.org/10.1179/174328406X109212.
172. Campanelli, L.C. A Review on the Recent Advances Concerning the Fatigue Performance of Titanium Alloys for Orthopedic Applications. *J. Mater. Res.* **2021**, *36*, 151–165. https://doi.org/10.1557/s43578-020-00087-0.
173. dos Santos, A.; Campanelli, L.C.; Da Silva, P.S.C.P.; Vilar, R.; de Almeida, M.A.M.; Kuznetsov, A.; Achete, C.A.; Bolfarini, C. Influence of a Femtosecond Laser Surface Modification on the Fatigue Behavior of Ti-6Al4V ELI Alloy. *Mater. Res.* **2019**, *22*. https://doi.org/10.1590/1980-5373-MR-2019-0118.
174. Potomati, F.; Campanelli, L.C.; Da Silva, P.S.C.P.; Simões, J.G.A.B.; de Lima, M.S.F.; Damião, Á.J.; Bolfarini, C. Assessment of the Fatigue Behavior of Ti-6Al-4V ELI Alloy with Surface Treated by Nd:YAG Laser Irradiation. *Mater. Res.* **2019**, *22*, 1–5. https://doi.org/10.1590/1980-5373-MR-2019-0016.
175. Liu, W.; Liu, S.; Wang, L. Surface Modification of Biomedical Titanium Alloy: Micromorphology, Microstructure Evolution and Biomedical Applications. *Coatings* **2019**, *9*, 249. https://doi.org/10.3390/coatings9040249.