Effects of Process Parameters on the Corrosion Resistance and Biocompatibility of Ti6Al4V Parts Fabricated by Selective Laser Melting

Shibo Xiang, Yanping Yuan,* Chengyu Zhang, and Jimin Chen

ABSTRACT: Excellent biocompatibility and corrosion resistance of implants are essential for Ti6Al4V parts fabricated by selective laser melting (SLM) for biomedical applications. To achieve better corrosion resistance and biocompatibility of Ti6Al4V parts, the effects of SLM processing parameters on the corrosion resistance and the biocompatibility of Ti6Al4V parts are investigated by changing the scanning speeds and laser powers. The detailed influence mechanism of processing parameters on the properties of Ti6Al4V parts is studied from two aspects, including microstructure and defects. It is found that the corrosion resistance and biocompatibility of Ti6Al4V parts can be adjusted by changing the scanning speed and the laser power due to the constituent phase and the number and size of defect holes of Ti6Al4V parts. Compared with the laser power, the scanning speed has a stronger influence on the performance of the part, which can be used as “coarse tuning” based on the performance requirements. At the scanning speed of 1100 mm/s and the laser power of 280 W, Ti6Al4V parts with better corrosion resistance can be obtained. Ti6Al4V parts with better biocompatibility are fabricated at the scanning speed of 1200 mm/s and the laser power of 200 W.

1. INTRODUCTION

Nowadays, artificial implants are extensively applied to replace damaged or diseased parts of human bone tissue, and the global bone repair market has huge potential.1,2 Metals used as implant materials are usually stainless steel,3 cobalt–chromium alloy,4 and titanium alloy.5 Compared with stainless steel and cobalt–chromium alloys, titanium alloys exhibit a lower elasticity modulus, which avoids stress shielding. Titanium alloys are widely used in the medical field due to their excellent mechanical properties6,7 and biocompatibility.8,9 Due to the personalized characteristics of bone tissue engineering, the personalized manufacturing of implants is urgently needed. Due to its layer-by-layer processing principle, three-dimensional (3D) printing technology has unique advantages in the personalized manufacturing of implants. Titanium alloy implants are usually fabricated by selective laser melting (SLM), which can effectively shorten the manufacturing cycles, improve material utilization, and fabricate complex personalized parts.10–12

Excellent biocompatibility and corrosion resistance of implants are the essential requirements for medical applications. The corrosion resistance and biocompatibility of implants are also vital properties for Ti6Al4V parts fabricated by SLM for biomedical applications. The corrosion of implants caused by the physiological environment results in the precipitation of metallic ions and the destruction of implant surface morphology, leading to not only an inflammatory reaction but also organ damage.17,18 The biocompatibility of implants is the most basic and important performance after implantation. Hence, it is necessary to study the corrosion resistance and biocompatibility of implants. The corrosion resistance of Ti6Al4V parts is investigated in various solutions.19–22 Heakal et al. demonstrated that the increase in azide concentration in a solution accelerated the corrosion of Ti6Al4V parts.19 Sharma et al. reported that better corrosion resistance of Ti6Al4V parts fabricated by SLM could be obtained in NaCl and NaOH than in H2SO4.20 Corrosion resistance of cast Ti6Al4V parts could be improved due to the formation of a passive film.21 However, there are relatively fewer studies about the corrosive behavior of Ti6Al4V parts fabricated by SLM in the simulated body fluid. In addition, the processing parameters are also critical for the properties of Ti6Al4V parts fabricated by SLM.12,23,24 Lu et al. found that Ti6Al4V parts fabricated by SLM had better corrosion resistance (the corrosion voltage of −0.352 V)23 at the laser
2. MATERIALS AND METHODS

2.1. Materials and Sample Preparation. Ti6Al4V alloy spherical powder produced by the gas atomization method (EOS company, Germany) is used in our experiments. The particle size of powder ranges from 25 to 57 μm and the average size is about 38 μm. The chemical composition of the material is shown in Table 1, and its morphology and particle size distribution are shown in Figure 1. Different Ti6Al4V parts fabricated by EOS M280 (EOS company, Germany) are obtained by changing the scanning speed and the laser power. The experimental parameters of the scanning speed (v), the laser power (P), the hatch distance (d), and the layer thickness (h) are shown in Table 2. Ti6Al4V samples (10 mm × 10 mm × 10 mm) are obtained by changing the scanning speed and the laser power. These are then abraded with silicon carbide (SiC) papers (grade from 240 to 2000), immersed in the Keller reagent (95 mL of water, 2.5 mL of HNO3, 1.5 mL of HCl, 1.0 mL of HF), and then ultrasonically cleaned with ethanol and deionized water for 10 min. The surface morphology is obtained by an optical microscope (OM) and scanning electron microscope (SEM). The surface morphology is obtained by an optical microscope (OM) and scanning electron microscope (SEM).

2.2. Corrosion Behavior. The electrochemical test is used to evaluate the corrosion resistance of Ti6Al4V parts fabricated by SLM. A CHI660D electrochemical workstation and 0.9% sodium chloride solution as an electrolyte are used in our experiments. Potentiodynamic polarization is tested in an electrochemical cell with the three-electrode system, which consists of a Ti6Al4V sample working electrode (10 mm × 10 mm × 10 mm), a platinum counter electrode, and a saturated calomel electrode with a Luggin capillary bridge. The experiments are performed at room temperature, and the distance between the Luggin capillary and the surface of the working electrode is fixed at 2 mm. According to the ISO10271-2011 standard, the potentiodynamic current/potential curves are recorded by a C view software with the scanning speed of 10 mV/s from −1.6 to 1.5 V. When the electrochemical reaction is in equilibrium, the sample is in a self-corrosion state, and the net current is not accumulated. When the system is out of the equilibrium state, the amount of material released from the cathode is proportional to the current strength and conduction time. Hence, the corrosion rate is assessed using the corrosion current density. The potential—current density curve (as a logarithm of current in the form of Tafel graph), open-circuit potential, and corrosion current density are obtained.

2.3. Biocompatibility. In vitro cytotoxicity is used to characterize the biological properties of Ti6Al4V parts. The 3-(4,5-dimethylthiazol-2-yl)-2,5-diphenyltetrazolium bromide (MTT) method is used to assess the cytotoxicity of the material. A microplate reader is used to obtain the absorption value of MTT dissolved in dimethyl sulfoxide. The absorbance value can reflect the number of surviving cells and the strength of cell metabolic activity. The relative growth rate (RGR) of the cells is calculated based on the absorbance value. The samples are extracted in a cell culture medium containing 10% calf serum for 24 h at the ratio of 1.25 cm²:1 mL (surface area of parts: extraction medium) at 37 °C. Mouse fibroblasts L929 are used to subculture the vigorously growing cells for 48–72 h in the experiment. The prepared 1 × 10⁵/mL cell suspension is inoculated on a 96-hole plate, and blank control, negative control, positive control, and material group are set up. Each group is equipped with at least six holes, and 100 μL of the cell suspension is inoculated for each hole. After being cultured in a 5% CO₂ incubator for 24 h, the original culture medium is discarded. The blank control group is added with a fresh cell culture medium. The negative control group was added with...
high-density polyethylene extract. The positive control group is added with 5% dimethylsulfoxide (DMSO). The material group is added with the Ti6Al4V part extract (divided into two groups, 100 and 50% extract), and 100 μL of the Ti6Al4V part extract is added in each hole, and then put in a 5% CO2 incubator for 24 h. After discarding the culture medium in the net hole, 50 μL of the MTT solution with a mass concentration of 1 g/L is added to each hole. After 2 h of continuous culture, the liquid in the net hole is discarded. One hundred microliters of isopropanol is then added and mixed evenly. Finally, the absorbance at 570 and 650 nm wavelength of the enzyme standard instrument is obtained and the relative value-added rate is calculated according to the formula

\[ \text{RGR} = \left( \frac{A_{570\text{ nm}} - A_{650\text{ nm}}}{A_{570\text{ nm}} - A_{650\text{ nm}}} \right) \times 100 \]

where RGR is the relative growth rate (%), A is the absorbance of the test group (negative and positive groups), and \( A_{B} \) is the absorbance of the blank control group.

### 3. RESULTS AND DISCUSSION

#### 3.1. Effects of the Scanning Speed

In this experiment, Ti6Al4V parts are fabricated by SLM parameters as follows: the scanning speed \( v = 1000, 1100, 1200, 1300, \) and 1400 mm/s, the laser power \( P = 280 \text{ W} \), the hatch distance \( h = 0.14 \text{ mm} \), and the layer thickness \( d = 0.03 \text{ mm} \). The corrosion behavior of Ti6Al4V parts fabricated by SLM is evaluated by an electrochemical test. Figure 2 shows the self-corroding Tafel potentiodynamic polarization curves of five groups of Ti6Al4V parts. The self-corrosion potential is a stable potential when the system is not subjected to external polarization. The higher the self-corrosion potential, the smaller the corrosion tendency. At the scanning speed of 1100 mm/s, the self-corrosion potential of the Ti6Al4V part is about \(-146.2 \text{ mV}\), showing the lowest corrosion tendency. At a scanning speed of 1300 mm/s, the self-corrosion potential is \(-116.2 \text{ mV}\) and the related corrosion tendency is the greatest. The self-corrosion potential only reflects the stability of the system.

The performance of corrosion dynamics is characterized by corrosion current density. Table 3 shows the measured values of the corrosion current density and self-corrosion potential of the five groups of Ti6Al4V parts. With the increase in the scanning speed, the corrosion resistance first improves and then degrades gradually. At the scanning speeds of 1000, 1300, and 1400 mm/s, the corrosion current density is relatively larger, \(3.486 \times 10^{-5}\), \(3.477 \times 10^{-5}\), and \(3.439 \times 10^{-5}\) A/cm², respectively. At the scanning speeds of 1100 and 1200 mm/s, the corrosion current densities of the prepared parts are about \(2.507 \times 10^{-5}\) and \(2.701 \times 10^{-5}\) A/cm², respectively. The larger corrosion current density means a larger corrosive quantity. When the scanning speed increases from 1000 to 1100 mm/s, the corrosion current density reaches the minimum value \(2.507 \times 10^{-5}\) A/cm². When the scanning speed exceeds 1100 mm/s, the corrosion current density increases. Hence, from

---

**Table 2. Experimental Parameters of the Scanning Speed and the Laser Power**

| number | \( v \) (mm/s) | \( P \) (W) | \( d \) (mm) | \( h \) (mm) |
|-------|----------------|-------------|-------------|-------------|
| 1     | 1000           | 280         | 0.14        | 0.03        |
| 2     | 1100           | 280         | 0.14        | 0.03        |
| 3     | 1200           | 280         | 0.14        | 0.03        |
| 4     | 1300           | 280         | 0.14        | 0.03        |
| 5     | 1400           | 280         | 0.14        | 0.03        |
| 6     | 1200           | 200         | 0.14        | 0.03        |
| 7     | 1200           | 240         | 0.14        | 0.03        |
| 8     | 1200           | 320         | 0.14        | 0.03        |
| 9     | 1200           | 360         | 0.14        | 0.03        |

**Table 3. Tafel Curve Measurement Result**

| parameter | corrosion rate (mV/s) | self-corrosion potential (mV) | corrosion current density (A/cm²) |
|-----------|-----------------------|-------------------------------|----------------------------------|
| 1 (1000 mm/s) | 10                    | -121.2                        | \(3.486 \times 10^{-5}\) |
| 2 (1100 mm/s) | 10                    | -146.2                        | \(2.507 \times 10^{-5}\) |
| 3 (1200 mm/s) | 10                    | -124.3                        | \(2.701 \times 10^{-5}\) |
| 4 (1300 mm/s) | 10                    | -116.2                        | \(3.477 \times 10^{-5}\) |
| 5 (1400 mm/s) | 10                    | -126.9                        | \(3.439 \times 10^{-5}\) |
the perspective of corrosion potential and corrosion current density, Ti6Al4V parts fabricated at 1100 mm/s scanning speed have better corrosion resistance. Hence, the corrosion resistance of Ti6Al4V parts can be adjusted by changing the scanning speed.

To evaluate the biological performance of Ti6Al4V parts, cell culture and proliferation are also investigated in this study. Figure 3 depicts the morphology of L929 cells cultured in different extracts for 24 h: (a) the blank control group, (b) the negative control group, (c) the positive control group, (d) 1000 mm/s, (e) 1100 mm/s, (f) 1200 mm/s, (g) 1300 mm/s, and (h) 1400 mm/s. Cell morphologies shown in Figure 3a,b are similar, while the cells shown in Figure 3c have a round shape. The validity of the experiment is substantiated by cell morphologies shown in Figure 3a-c. When the scanning speed increases from 1000 to 1400 mm/s, the cell round shrinkage rate is about 13, 15, 8, 5, and 23%. Hence, the scanning speed had a great influence on the morphology of L929 cells. The normal rate of cell morphology is relatively higher at the scanning speed of 1300 mm/s. As shown in Figure 4, when the scanning speed is 1300 mm/s, the cell proliferation rate is the largest (74.4%), and when the scanning speed is 1400 mm/s, the cell proliferation rate is the smallest (65.2%). Hence, the biological performance of Ti6Al4V parts can be adjusted by changing the scanning speed.

To understand the detailed influence mechanism of scanning speed on the corrosion resistance and biological performance, the SEM images of Ti6Al4V parts fabricated at different scanning speeds are shown in Figure 5. The above experimental phenomena are attributed to the constituent phase and the number and size of defect holes of Ti6Al4V parts. As shown in Figure 5, at the scanning speeds of 1000 mm/s, more acicular α'-Ti phase and a small number of defect holes with the size of about 6 μm are observed on the surface of Ti6Al4V parts. It is known that the acicular α'-Ti phase is easily dissolved and favorable for cell growth and attachment.31 In addition, the large defects hole not only increase the contact area between the etching solution and Ti6Al4V parts but also hinder the proliferation of cells and release toxic ions, resulting in a low relative growth rate and a high round shrinkage rate of cells on the surface of the part. At the scanning speed of 1100 mm/s, the β'-Ti phase is most commonly observed and defects holes are relatively rare. It is known that the β'-Ti phase plays an important role in resisting dissolution.31 However, there are few α'-Ti phases conducive to cell growth and attachment. Hence, Ti6Al4V parts fabricated at 1100 mm/s scanning speed have better corrosion resistance but poor biocompatibility. At the scanning speed of 1200 mm/s, relatively more β'-Ti phase and a small amount of α'-Ti phase are observed and a certain number of defect holes with larger size are also obtained on the surface of Ti6Al4V parts. Due to the existing big holes and α'-Ti phase, the corrosion resistance of Ti6Al4V parts is reduced, compared with the situation of 1100 mm/s. On the other hand, the α'-Ti phase leads to the acceleration of cell proliferation and an increase in the relative growth rate. At the scanning speed of 1300 mm/s, more acicular α'-Ti phase and tiny holes are observed, which is conducive to the adhesion and proliferation of the cells and increasing the relative growth rate of the cells. At the scanning speed of 1400 mm/s, more acicular α'-Ti phase and a lot of defect holes (both large holes and tiny holes) are observed. The Ti6Al4V parts fabricated at the scanning speed of 1400 mm/s are with the worst corrosion resistance and biocompatibility.

3.2. Effects of Laser Power. The Ti6Al4V parts are fabricated by SLM parameters as follows: the laser power $P = 200, 240, 280, 320$, and $360$ W; the scanning speed $v = 1200$ mm/s; the hatch distance $h = 0.14$ mm; and the layer thickness $d = 0.03$ mm. The corrosion behavior is evaluated by an electrochemical test. Figure 6 shows the self-corroding Tafel potentiodynamic polarization curves of five groups of Ti6Al4V samples. The self-corrosion potential of Ti6Al4V parts sharply increases and then rapidly decreases with the increase in the laser power. The self-corrosion potential is $-264.9$ mV at the laser power of $320$ W, which indicates the smallest corrosion tendency. At the laser power of $360$ W, the self-corrosion...
potential is \(-102.5\) mV, exhibiting the highest corrosion tendency.

Table 4 shows the measured values of the corrosion current density and self-corrosion potential of five groups of Ti6Al4V parts. As the laser power increases, the corrosion current density shows oscillating behavior: decreasing sharply, then increasing quickly, and finally rapidly decreasing. At the laser power of 200, 240, and 320 W, the corrosion current density is relatively larger \((3.003 \times 10^{-5}, 3.171 \times 10^{-5}, \text{ and } 3.356 \times 10^{-5} \text{ A/cm}^2)\) and the corrosion resistance is relatively lower. At the laser power of 360 W, the relatively smaller corrosion current density \((2.801 \times 10^{-5} \text{ A/cm}^2)\) indicates better corrosion resistance. The corrosion current density reaches the minimum \((2.701 \times 10^{-5} \text{ A/cm}^2)\) at 280 W laser power, and the Ti6Al4V parts exhibit the best corrosion resistance. Hence, the corrosion resistance of Ti6Al4V parts can be adjusted by changing the laser power.

Figure 7 depicts the cell morphology of L929 cells cultured in different extracts for 24 h. Figure 7a shows the cell morphology of the blank control. As shown in Figure 7b, the cell morphology of the negative control group is normal, which is similar to the cell morphology given in Figure 7a. While the morphology of the cells of the positive control is rounded, as shown in Figure 7c. The cell morphology shown in Figure 7a–c proves that the experiment is effective. Figure 7d–h shows the difference in cell morphology on the surface of Ti6Al4V parts fabricated under different laser powers. When the laser power is increased from 200 to 360 W, the cell round shrinkage rates are about 11, 10, 8, 7, and 10%. The changes in cell proliferation rate in five groups of different laser powers are investigated in this study, as shown in Figure 8. It is easily found that the changing trend of cell proliferation rate is consistent with that of cell morphology. With the increase in laser power, the cell proliferation rate first slowly decreases and then slowly increases. When the laser power is 280 W, the minimum cell proliferation rate is obtained \((70.8\%)\). When the laser power is 200 W, the maximum cell proliferation rate is 75.5%. Hence, the biological performance of Ti6Al4V parts can be adjusted by changing the laser power.

As shown in Figure 9, Ti6Al4V parts fabricated by SLM at different laser powers have different microstructures and defects, causing different corrosion resistance and biological properties of Ti6Al4V parts. As shown in Figure 9, at the laser power of 200, 240, and 320 W, relatively more \(\alpha’\)-Ti phase and more hole defects appear on the surface of Ti6Al4V parts, which leads to the reduction of corrosion resistance. At the laser power of 280 W, relatively more \(\beta\)-Ti phase and relatively fewer defects are observed, Ti6Al4V parts are with better corrosion resistance. Due to the \(\beta\)-Ti phase, \(\alpha’\)-Ti phase, and hole defects, the corrosion resistance of Ti6Al4V parts is
relatively weakened at 360 W laser power, compared with the situation of 280 W. For the biological properties of Ti6Al4V parts, at the laser power of 200, 320, and 360 W, $\alpha'$-Ti phase and tiny defect holes are observed, which is conducive to the adhesion and proliferation of cells and increase in the relative growth rate. Hence, Ti6Al4V parts have relatively a higher relative growth rate. However, defect holes of Ti6Al4V parts cause the release of toxic ions. At the laser power of 240 W, relatively fewer $\alpha'$-Ti phase and relatively more $\beta$-Ti phase are obtained on the surface of Ti6Al4V parts, which leads to a low relative growth rate of the surface cells. Due to the existing big holes, the cell round shrinkage rate is relatively higher. At the laser power of 280 W, relatively fewer $\alpha'$-Ti phase is observed and there are almost no hole defects.

4. CONCLUSIONS

Selective laser melting (SLM), as one of the typical additive manufacturing technologies, has been widely used in the medical field, especially for implant applications. The corrosion resistance and the biocompatibility of implants are vital properties for Ti6Al4V parts fabricated by SLM for biomedical applications. To achieve better corrosion resistance and biocompatibility of Ti6Al4V parts, the effects of SLM processing parameters on the corrosion resistance and the biocompatibility of Ti6Al4V parts are investigated by changing the scanning speeds (1000, 1100, 1200, 1300, and 1400 mm/...
s) and the laser powers (200, 240, 280, 320, and 360 W). The experimental results show that (1) the corrosion resistance and biocompatibility of Ti6Al4V parts can be regulated by changing the scanning speed and the laser power due to the constituent phase and the number and size of defect holes of Ti6Al4V parts; (2) the large number of defect holes leads to a relatively lower growth rate and a high round shrinkage rate of cells on the surface of the part, due to the increasing of the contact area (between the etching solution and Ti6Al4V parts) and the release of the toxic ions; (3) tiny holes are conducive to the adhesion and proliferation of the cells and the increase in the relative growth rate of the cells; (4) compared with laser power, the scanning speed has a stronger influence on the performance of the part; (5) at the scanning speed of 1100 mm/s, the laser power of 280 W, the hatch distance of 0.14 mm, and the layer thickness of 0.03 mm, Ti6Al4V parts show better corrosion resistance; (6) Ti6Al4V parts with better biocompatibility are fabricated at the scanning speed of 1200 mm/s, the laser power of 200 W, the hatch distance of 0.14 mm, and the layer thickness of 0.03 mm, and the cell proliferation rate is the largest (75.5%). The proposed research is applied to improve the biological activity of titanium alloy implants, which can increase the surgical success rate of implants and promote the clinical application of implants. However, the more detailed influence mechanism of scanning speed on the properties of Ti6Al4V parts is not investigated in this study, as it is still being investigated.

**AUTHOR INFORMATION**

**Corresponding Author**

Yanping Yuan – Institute of Laser Engineering, Faculty of Materials and Manufacturing, Beijing University of Technology, Beijing 100124, China; Key Laboratory of Trans-Scale Laser Manufacturing Technology, Beijing University of Technology, Ministry of Education, Beijing 100124, China; Beijing Engineering Research Center of 3D Printing for Digital Medical Health, Beijing University of Technology, Beijing 100124, China; Email: ypyuan@bjut.edu.cn

**Authors**

Shibo Xiang – Institute of Laser Engineering, Faculty of Materials and Manufacturing, Beijing University of Technology, Beijing 100124, China; Key Laboratory of Trans-Scale Laser Manufacturing Technology, Beijing University of Technology, Ministry of Education, Beijing 100124, China; Beijing Engineering Research Center of 3D Printing for Digital Medical Health, Beijing University of Technology, Beijing 100124, China; ○ orcid.org/0000-0002-8032-0770

Chengyu Zhang – Institute of Laser Engineering, Faculty of Materials and Manufacturing, Beijing University of Technology, Beijing 100124, China; Key Laboratory of Trans-Scale Laser Manufacturing Technology, Beijing University of Technology, Ministry of Education, Beijing 100124, China; Beijing Engineering Research Center of 3D Printing for Digital Medical Health, Beijing University of Technology, Beijing 100124, China; ○ orcid.org/0000-0002-2735-3805

Jimin Chen – Institute of Laser Engineering, Faculty of Materials and Manufacturing, Beijing University of Technology, Beijing 100124, China; Key Laboratory of Trans-Scale Laser Manufacturing Technology, Beijing University of Technology, Ministry of Education, Beijing 100124, China; ○ orcid.org/0000-0002-8032-0770

University of Technology, Ministry of Education, Beijing 100124, China; Beijing Engineering Research Center of 3D Printing for Digital Medical Health, Beijing University of Technology, Beijing 100124, China

Complete contact information is available at: https://pubs.acs.org/10.1021/acsomega.1c06246

**Notes**

The authors declare no competing financial interest.

**ACKNOWLEDGMENTS**

This research was financially supported by the National Natural Science Foundation of China (NSFC) (Grant Nos. 52175374 and 51805014) and the Scientific Research Program of Beijing Municipal Education Commission (Grant No. KM201810005012).

**REFERENCES**

(1) Wang, X.; Xu, S.; Zhou, S.; Wei, X.; Yi, M. X. J. Topological Design and Additive Manufacturing of Porous Metals for Bone Scaffolds and Orthopaedic Implants: A Review. *Biomaterials* 2016, 83, 127–141.

(2) Stewart, C.; Akhavan, B.; Wise, S. G.; Bilek, M. A review of biomimetic surface functionalization for bone-integrating orthopedic implants: Mechanisms, current approaches, and future directions. *Prog. Mater. Sci.* 2019, 106, No. 105088.

(3) Ibrahim, M. Z.; Sarhan, A.; Kuo, T. Y.; Yusof, F.; Hamdi, M. Physics, characterization and hardness enhancement of amorphous Fe-based metallic glass laser cladded on nickel-free stainless steel for biomedical implant application. *Mater. Chem.* 2019, 235, No. 121745.

(4) Srivastava, A.; Bidra, A. S. Milled cobalt-chromium metal framework with veneered porcelain for a complete-arch fixed implant-supported prosthesis: A clinical report. *J. Prosthet. Dent.* 2020, 123, 367–372.

(5) Zhang, L.; Chen, L. A Review on Biomedical Titanium Alloys: Recent Progress and Prospect. *Adv. Eng. Mater.* 2019, 21, No. 1801215.

(6) Ataee, A.; Li, Y.; Fraser, D.; Song, G.; Wen, C. Design, Anisotropic Ti-6Al-4V gyroid scaffolds fabricated by electron beam melting (EBM) for bone implant applications. *Mater. Chem.* 2018, 137, 345–354.

(7) Khorsan, M.; Ghasemi, A. H.; Awan, U. S.; Hadavi, E.; Gibson, L. A. A study on surface morphology and tension in laser powder bed fusion of Ti-6Al-4V. *Int. J. Adv. Manuf. Technol.* 2020, 111, 2891–2909.

(8) Shi, Q.; Sun, Y.; Yang, S.; Dessel, J. V.; Politis, C. Failure analysis of an in-vivo fractured patient-specific Ti6Al4V mandible reconstruction plate fabricated by selective laser melting. *Eng. Failure Anal.* 2021, 124, No. 105335.

(9) Bartolomeu, F.; Dourado, N.; Pereira, F.; Alves, N.; Miranda, G.; Silva, F. S. Additive manufactured porous biomaterials targeting orthopedic implants: A suitable combination of mechanical, physical and topological properties. *Mater. Sci. Eng., C* 2020, 107, No. 110342.

(10) Blackford, B.; Zak, G.; Kim, I. Y. The effect of scan path on thermal gradient during selective laser melting. *Int. J. Adv. Manuf. Technol.* 2020, 110, 1261–1274.

(11) Singla, A. K.; Banerjee, M.; Sharma, A.; Singh, J.; Goyal, D. K. Selective laser melting of Ti6Al4V alloy: Process parameters, defects and post-treatments. *J. Manuf. Processes* 2021, 64, 161–187.

(12) Qian, C.; Xu, H.; Zhong, Q. The influence of process parameters on corrosion behavior of Ti6Al4V alloy processed by selective laser melting. *J. Laser Appl.* 2020, 32, No. 032010.

(13) Jamshidi, P.; Arizistabil, M.; Kong, W.; Villapun, V.; Attallah, M. M. Selective Laser Melting of Ti-6Al-4V: The Impact of Post-processing on the Tensile, Fatigue and Biological Properties for Medical Implant Applications. *Mater. Res. Express* 2020, 13, No. 2813.
Barabás, R. Tissue Integration and Biological Cellular Response of SLM-Manufactured Titanium Scaffolds. *Metals* 2020, 10, No. 1192.

Sovanpreecha, C.; Alabort, E.; Tang, Y. T.; Panwisawas, C.; Manonukul, A. A novel low-modulus titanium alloy for biomedical applications: a comparison between selective laser melting and metal injection moulding. *Mater. Sci. Eng., A* 2021, 1, No. 141081.

Mohammed, M. T.; Semelov, V. G.; Sotov, A. V. SLM-built titanium materials: great potential of developing microstructure and properties for biomedical applications: A Review. *Mater. Res. Express* 2019, 6, No. 122006.

Suwanpreecha, C.; Alabort, E.; Tang, Y. T.; Panwisawas, C.; Manonukul, A. A novel low-modulus titanium alloy for biomedical applications: a comparison between selective laser melting and metal injection moulding. *Mater. Sci. Eng., A* 2021, 1, No. 141081.

Mohammed, M. T.; Semelov, V. G.; Sotov, A. V. SLM-built titanium materials: great potential of developing microstructure and properties for biomedical applications: A Review. *Mater. Res. Express* 2019, 6, No. 122006.

Manam, N. S.; Harun, W.; Shri, D.; Ghani, S.; Kurniawan, T.; Ismail, M. H.; Ibrahim, M. Study of corrosion in biocompatible metals for implants: A review. *J. Alloys Compd.* 2017, 701, 698–715.

Dai, N.; Zhang, L. C.; Zhang, J.; Chen, Q.; Wu, M. Corrosion behavior of selective laser melted Ti-6Al-4 V alloy in NaCl solution. *Corros. Sci.* 2016, 102, 484–489.

Heikal, F. E.; Ghoneim, A. A.; Mogoda, A. S.; Awad, K. Electrochemical behaviour of Ti–6Al–4V alloy and Ti in azide and halide solutions. *Corros. Sci.* 2011, 53, 2728–2737.

Sharma, A.; Oh, M. C.; Kim, J. T.; Srivastava, A. K.; Ahn, B. Investigation of electrochemical corrosion behavior of additive manufactured Ti–6Al–4V alloy for medical implants in different electrolytes—ScienceDirect. *J. Alloys Compd.* 2020, 830, No. 154620.

Alves, V. A.; Reis, R. Q.; Santos, I. C.; Souza, D. G.; Gonçalves, T. D.; Pereira-da-Silva, M. A.; Rossi, A.; Da Silva, L. A. In situ impedance spectroscopy study of the electrochemical corrosion of Ti and Ti-6Al-4V in simulated body fluid at 25 °C and 37 °C. *Corros. Sci.* 2009, 51, 2473–2482.

Lidia, B. Impact of Hydrogen Peroxide and Albumin on the Corrosion Behavior of Titanium Alloy (Ti6Al4V) in Saline Solution. *Int. J. Electrochem. Sci.* 2021, 16, No. 210244.

Lu, P.; Wu, M.; Liu, X.; Duan, W.; Han, J. Study on Corrosion Resistance and Bio-Tribological Behavior of Porous Structure Based on the SLM Manufactured Medical Ti6Al4V. *Met. Mater. Int.* 2019, 26, 1182–1191.

Dai, N.; Zhang, L. C.; Zhang, J.; Zhang, X.; Ni, Q.; Chen, Y.; Wu, M.; Yang, C. Distinction in corrosion resistance of selective laser melted Ti-6Al-4V alloy on different planes. *Corros. Sci.* 2016, 111, 703–710.

Ni, J.; Liu, F.; Yang, G.; Lee, G. H.; Chung, S. M.; Lee, I. S.; Chen, C. 3D-printed Ti6Al4V femoral component of knee: Improvements in wear and biological properties by AIP TiN and TiCrN coating. *J. Mater. Res. Technol.* 2021, 14, 2322–2332.

Cox, S. C.; Jamshidi, P.; Eisenstein, N. M.; Webber, M. A.; Burton, H.; Moakes, R. J. A.; Addison, O.; Attallah, M.; Shepherd, D. E. T.; Grover, L. M. Surface Finish has a Critical Influence on Biofilm Formation and Mammalian Cell Attachment to Additively Manufactured Prosthetics. *ACS Biomater. Sci. Eng.* 2017, 3, 1616–1626.

Xu, X.; Lu, Y.; Li, S.; Guo, S.; He, M.; Luo, K.; Lin, J. Copper-modified Ti6Al4V alloy fabricated by selective laser melting with proangiogenic and anti-inflammatory properties for potential guided bone regeneration applications. *Mater. Sci. Eng., C* 2018, 90, 198–210.

Ganbold, B.; Heo, S. J.; Koak, J. Y.; Kim, S. K.; Cho, J. Human Stem Cell Responses and Surface Characteristics of 3D Printing Co-Cr Dental Material. *Mater. Chem.* 2019, 12, No. 3419.

Ran, Q.; Yang, W.; Hu, Y.; Shen, X.; Yu, Y.; Xiang, Y.; Cai, K. Osteogenesis of 3D printed porous Ti6Al4V implants with different pore sizes. *J. Mech. Behav. Biomed. Mater.* 2018, 84, 1–11.

Ghosh, S.; Sylvester, A.; Sherman, W.; Shadi, H. Selective laser melted titanium alloys for hip implant applications: Surface modification with new method of polymer grafting. *J. Mech. Behav. Biomed. Mater.* 2018, 87, 312–324.

Manam, N. S.; Harun, W.; Shri, D.; Ghani, S.; Kurniawan, T.; Ismail, M. H.; Ibrahim, M. Study of corrosion in biocompatible metals for implants: A review. *J. Alloys Compd.* 2017, 701, 698–715.