Journal of Information Systems Engineering and Management
2025, 10(47s)
e-ISSN: 2468-4376
https://www.jisem-journal.com/

Research Article

Micromachining of Co-Cr-Mo alloy Surface with Femtosecond laser

Ljerka Slokar Benić [1*], Andreja Carek [2], Hrvoje Skenderović [3]
[1] *Department of Physical Metallurgy, University of Zagreb Faculty of Metallurgy, Sisak, Croatia.*
[2] *Department of Fixed Prosthodontics, University of Zagreb School of Dental Medicne, Zagreb, Croatia.*
[3] *Center for Advanced Laser Techniques, Institute of Physics. Zagreb, Croatia.*
**Corresponding Author Email: slokar@simet.unizg.hr*

ARTICLE INFO

Received: 15 Dec 2024
Revised: 17 Feb 2025
Accepted: 27 Feb 2025

ABSTRACT

Micromachining with the femtosecond laser as a new technology for modifying the surface of various dental materials is attracting great interest and is constantly evolving. In this work, the material of interest was the Co-Cr-Mo casting alloy used in dentistry. This is because its use weakens the properties of dental appliances. They should therefore be improved. To this end, in this study, the surface of a cast Co-Cr-Mo dental alloy was micromachined with different parameters of the femtosecond laser, i.e. with three laser powers and three scanning speeds. The morphology was analyzed with a scanning electron microscope. The hardness was measured using the Vickers method. The results showed that the optimum morphology was achieved during micromachining with a laser power of 0.7 W and a scanning speed of 0.005 m/s.

Keywords: Dental alloy, femtosecond laser, hardness, micromachinig, morphology.

INTRODUCTION

Laser machining as a new technology for the production of micro/nanostructures has recently attracted a lot of attention. Compared to other methods for producing micro/nanostructured materials, micromachining with a laser offers several advantages, such as simpler equipment, the ability to process almost all types of materials, and easy customization of process parameters. There are different types of lasers, e.g. ultraviolet, nanosecond, picosecond and femtosecond lasers. Despite outstanding contributions to the development of laser technology in various industries, the application areas of laser technology are constantly expanding. Femtosecond laser machining has proven to be a particularly impressive method for producing various surface micro/nanostructures that are otherwise difficult to achieve.

Micromachining with a femtosecond laser was first demonstrated in 1994. The main feature of the femtosecond laser is that it can emit high-intensity pulses in a very short time [1]. Femtosecond laser machining involves an interaction between an ultrashort pulse of a focused high-power beam and the material. Thanks to the ultrashort pulse properties of femtosecond lasers, thermal effects during processing can be significantly reduced [2], [3].

The microstructure of the surface is of great importance for the behavior of materials in the environment and can be adapted to improve the effectiveness of the application. The roughness of the surface of biomaterials can improve the bonding between the two materials and create a reciprocal mechanical effect, i.e. improve the interaction between the implant and the tissue and simulate the natural cellular environment [4].

The surface treatment of alloys for the purpose of functionalizing dental implants showed an improvement in osseointegration and soft tissue attachment as well as a reduction in biofilm formation [5].

Co-Cr-Mo alloys are widely used in clinical practice due to their good mechanical properties, which guarantee the technical and functional properties of dental implants and result from a multiphase microstructure consisting of alpha phase and hardness-increasing carbides. In addition, the high chromium content leads to excellent corrosion resistance, which is closely related to biocompatibility. However, the use of Co-Cr-Mo alloys leads to microstructural

Journal of Information Systems Engineering and Management
2025, 10(47s)
e-ISSN: 2468-4376
https://www.jisem-journal.com/
Research Article

changes in the contact zone, which weakens their mechanical and corrosive properties. For this reason, various techniques, such as surface modification, are used [6]–[8].

The aim of this work was to investigate the influence of different parameters of micromachining the surface of a Co-Cr-Mo dental alloy with a femtosecond laser on the resulting morphology and Vickers hardness.

MATERIALS AND METHODS

Materials

This study investigates a cobalt-chromium-molybdenum-based alloy (Vitallium, Dentsply Sirona, USA) intended for the casting of removable partial denture frameworks. The chemical composition of the alloy is given in Table 1, according to the manufacturer's specifications.

Table 1: Chemical composition of experimental alloy

Element	Wt.%
Co	63.4
Cr	29.0
Mo	5.2
Mn, Si, C	<1.0

Nine samples of the test alloy were cast in the form of plates according to the ISO standard [9] in order to be micromachined with a femtosecond laser. All samples were metallographically prepared according to the standard procedure and then polished with an aluminum oxide powder suspension.

Femtosecond laser experiment

The schematic representation of the femtosecond laser experimental setup is shown in Figure 1.

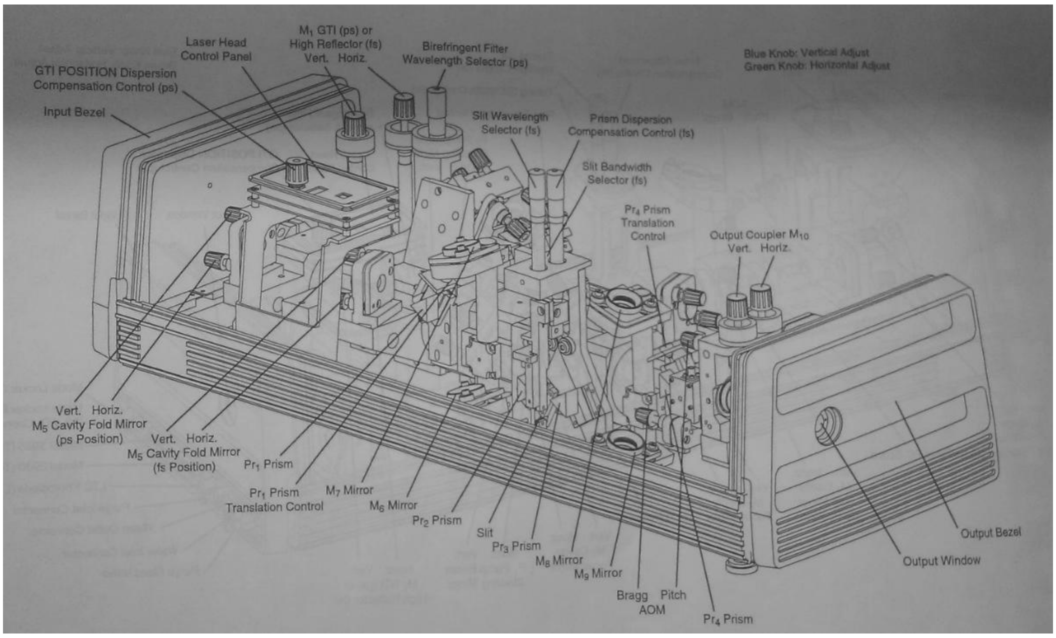


Figure 1. Schematic of femtosecond laser experimental setup

Micromachining with the femtosecond laser was performed in air, combining different laser parameters (Table 2). Three values of laser power (P) were combined with three scanning laser speeds (v).

Journal of Information Systems Engineering and Management
2025, 10(47s)
e-ISSN: 2468-4376
https://www.jisem-journal.com/

Research Article

Table 2: Parameters of laser micromachining

P, W	v, m/s
10.01	0.001
0.01	0.002
0.01	0.005
0.07	0.001
0.07	0.002
0.07	0.005
0.1	0.001
0.1	0.002
0.1	0.005

SEM analysis

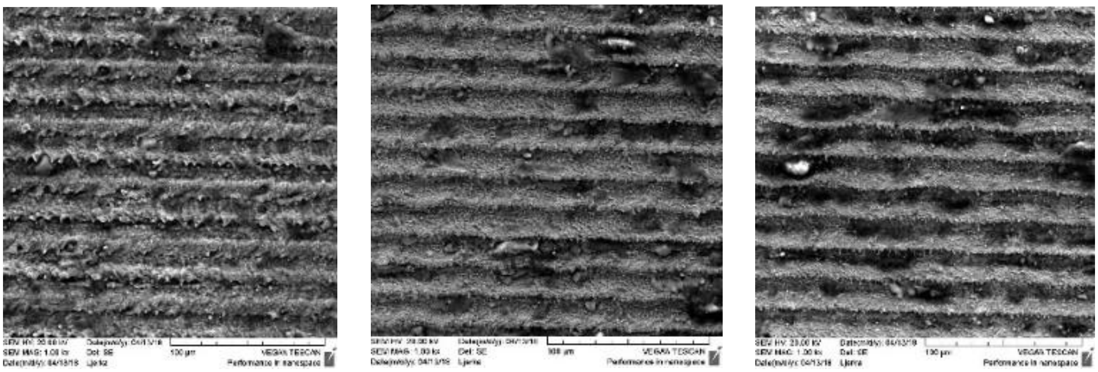
After femtosecond laser micromachining of polished dental castings made of Co-Cr-Mo alloy, the surface was analyzed with the VEGA TESCAN TS5136MM scanning electron microscope using secondary electron imaging.

Vickers hardness

The Vickers hardness (HV) of all samples of the experimental Co-Cr-Mo alloy was measured using the Leica VHMT Vickers hardness tester before and after micromachining with a femtosecond laser. A load of 19.60 N was applied for 10 s for all HV measurements. The hardness was measured at five random spots for each sample and the average HV2 value was calculated.

RESULTS AND DISCUSSION

Scanning electron microscopy was used to analyze the morphology of the lasered surfaces as a function of the laser power and the scanning laser speed. Figure 2 shows an alloy surface after micromachining with a scanning speed of 0.001, 0.002 and 0.005 m/s at a laser power of 0.01 W.



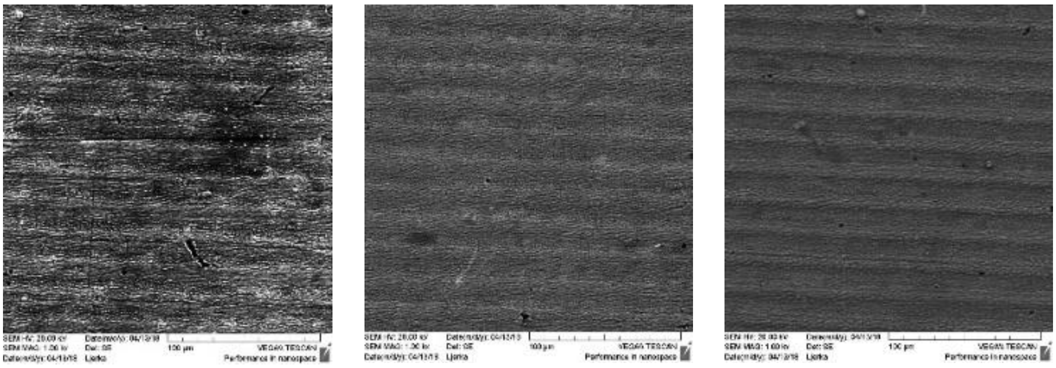
0.001 m/s 0.002 m/s 0.005 m/s

Figure 2. SEM images of the micromachined alloy surface with 0.01 W laser power

Figure 3 shows the alloy surface after micromachining with a scanning speed of 0.001, 0.002 and 0.005 m/s at an 01 laser power of 0.07 W.0

Journal of Information Systems Engineering and Management
2025, 10(47s)
e-ISSN: 2468-4376
https://www.jisem-journal.com/

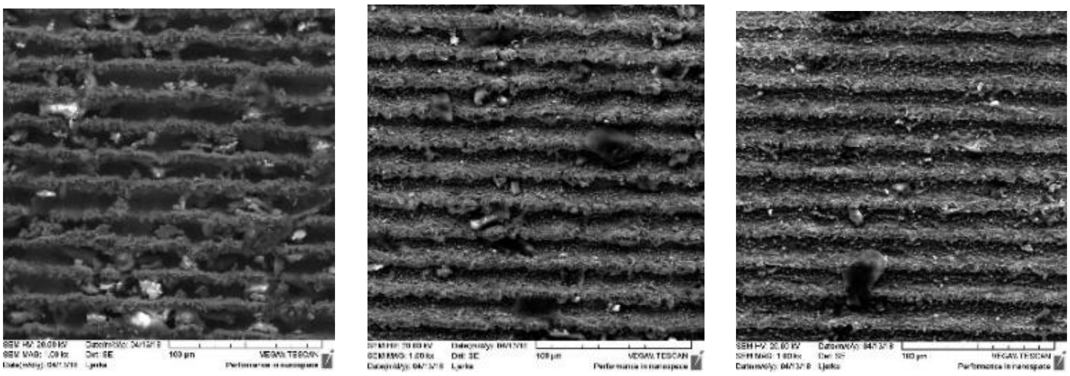
Research Article



0.001 m/s 0.002 m/s 0.005 m/s

Figure 3. SEM images of the micromachined alloy surface with 0.07 W laser power

Figure 4 shows an alloy surface after micromachining with a scanning speed of 0.001, 0.002 and 0.005 m/s at a maximum laser power of 0.1 W.



0.001 m/s 0.002 m/s 0.005 m/s

Figure 4. SEM images of the micromachined alloy surface with 0.1 W laser power

The SEM images showed significant changes in the surface morphology of the Co-Cr-Mo alloy after femtosecond laser treatment, indicating that all the adjusted laser parameters led to a change in the surface. After laser micromachining, various microstructural features such as craters, grooves and a textured pattern appeared depending on the laser parameters. It can be seen that the morphologies are characterized by laser-induced periodic surface structures (LIPSS) in the direction of laser scanning.

When the alloy surface was micromachined with the lowest laser power (0.01 W), flat microcraters and a slightly rough surface were formed on the surface. Small pits and microtextures can be seen on the SEM images (Fig. 2), with minimal thermal effects around the laser spot. When using the highest laser power (0.1 W), deep, well-defined craters and pronounced surface damage were formed on the surface (Fig. 4). A clear increase in surface roughness can also be recognized. However, when micromachining with mild laser power (0.07 W), the resulting texture is finer, without pronounced pores and damage. Fine microscopic indentations or pores with a regular arrangement are visible on the surface. Such pores can improve adhesion, which is useful for dental applications. The texture is uniform and has no sharp edges or irregularities that could affect the biocompatibility or performance of the alloy.

The scanning speed also plays an important role in changing the alloy morphology or surface characteristics. At lower scanning speeds (0.001 and 0.002 m/s), the laser beam had more time to interact with the material, resulting in a more pronounced surface change. Accordingly, the highest scanning speed (0.005 m/s), i.e. the shortest interaction time, resulted in flatter surface features.

Journal of Information Systems Engineering and Management
2025, 10(47s)
e-ISSN: 2468-4376
https://www.jisem-journal.com/
Research Article

The Vickers hardness of the experimental Co-Cr-Mo casting alloy was determined before and after femtosecond laser machining. The average values of Vickers hardness (HV2) for all samples measured after femtosecond laser micromachining are shown in Table 3.

Table 3: Hardness of samples micromachined by femtosecond laser

P, W	v, m/s	HV2
10.01	0.001	389
0.01	0.002	386
0.01	0.005	384
0.07	0.001	381
0.07	0.002	382
0.07	0.005	375
0.1	0.001	396
0.1	0.002	400
0.1	0.005	403

The Vickers hardness measurements showed that laser micromachining increased the hardness of the surface of the Co-Cr-Mo alloy. The untreated Co-Cr-Mo alloy had a hardness of approximately 371 HV2. After femtosecond laser treatment, the hardness varied depending on the laser parameters. Thus, the HV2 values were slightly increased by the medium laser power and the highest scanning speed. All other laser parameters led to a significant increase compared to the non-lasered surface. This can be attributed to the formation of a refined microstructure by the laser on the surface, i.e. the potential presence of mixed phase regions and the densification of the surface material, as well as the formation of a highly structured and possibly hardened surface layer due to the intense local heating and rapid cooling.

The dependence of the HV2 values on the scanning speed for all three laser powers is shown in Figure 5.

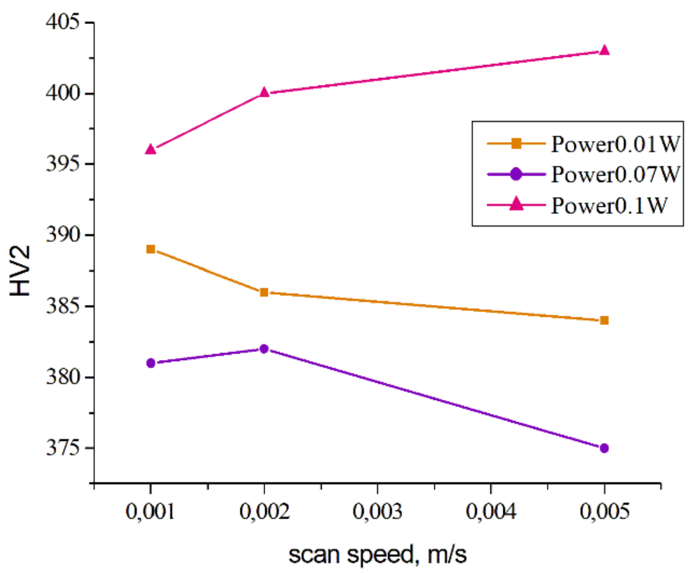


Figure 3. HV dependence on laser power

Figure 5 shows a different trend in HV2 values. The highest HV2 values were measured for samples lasered at the highest power of 0.1 W, and an increase in hardness with increasing laser speed can be seen. In contrast, when

Journal of Information Systems Engineering and Management
2025, 10(47s)
e-ISSN: 2468-4376
https://www.jisem-journal.com/
Research Article

lasering at the lowest power of 0.01 W, increasing the scanning speed led to a decrease in HV2 values. At the average laser power of 0.7 W, the lowest HV2 values were measured, which are close to the values of the non-lasered alloy, especially at the highest laser speed.

From the above results, it can be seen that a satisfactory surface morphology with minimal hardness change is achieved when micromachining this Co-Cr-Mo alloy with a laser power of 0.7 W and a scanning speed of 0.005 m/s.

CONCLUSION

This study demonstrates the potential of femtosecond laser micromachining for modifying the surface of Co-Cr-Mo alloys. The femtosecond laser micromachining significantly altered the surface morphology, since the surface roughness and the formation of microcraters and grooves were increased. The Vickers hardness testing revealed that laser treatment can enhance the hardness of the Co-Cr-Mo alloy.

The results suggest that femtosecond laser micromachining offers a precise and effective method for tailoring the surface properties of Co-Cr-Mo alloys for applications in dental implants. The findings also emphasize the importance of optimizing laser parameters to achieve the desired surface morphology and mechanical properties.

Of the laser parameters used, the best results in terms of the surface morphology of the test alloy and its hardness were achieved during micromachining with a laser power of 0.07 W at a scanning speed of 0.005 m/s..

REFERENCES

[1] Yang, L. et al., 2019, The fabrication of micro/nano structures by laser machining. *Nanomaterials*, 9(12), 1789

[2] He, Z. et al., 2024, Metal Material Processing Using Femtosecond Lasers: Theories, Principles, and Applications. *Materials*, 17(14), 3386

[3] Meng, L. et al., 2022, Femtosecond Laser Treatment for Improving the Corrosion Resistance of Selective Laser Melted 17-4PH Stainless Steel. *Micromachines*, 13(7), 1089

[4] Henriques, B., Fabris, D., Voisiat, B. and Lasagni, A.F., 2023, Multi-Scale Structuring of CoCrMo and AZ91D Magnesium Alloys Using Direct Laser Interference Patterning. *Metals*, 13(7), 1248

[5] Han, J., Zhang, F., Van Meerbeek, B., Vleugels, J., Braem, A. and Castagne, S., 2021, Laser surface texturing of zirconia-based ceramics for dental applications: A review. *Materials Science and Engineering C*, 123, 112034

[6] Carek, A., Zivko Babic, J., Schauperl, Z. and Badel, T., 2011, Mechanical Properties of Co-Cr Alloys for Metal Base Framework. *International Journal of Prosthodontics and Restorative Dentistry*, 1(1), 13–19

[7] Okur, S., 2009, Structural, compositional and mechanical characterization of plasma nitrided CoCrMo alloy. Master Thesis, Graduate School of Engineering and Sciences of İzmir Institute of Technology, 1-107

[8] Vidyasagar, K.E.C. and Kalyanasundaram, D., 2024, Enhanced corrosion resistance of CoCrMo by laser-based surface modification. *Surface Engineering and Applied Electrochemistry*, 40(1), 100–111

[9] ISO NTERNATIONAL STANDARD 16744:2003, Dentistry - Base metal materials for fixed dental restorations. 2003, p24