SERBIATRIB '25

19th International Conference on Tribology

14 – 16 May 2025, Kragujevac, Serbia

PROCEEDINGS

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Serbian Tribology Society

University of Kragujevac
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EFFECT OF ELECTRON BEAM PROCESSING PARAMETERS ON THE SURFACE ROUGHNESS OF TITANIUM SAMPLES

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Abstract: *This study investigates the effect of the number of electron beam passes on the surface roughness of titanium samples processed with a beam current of 0.8 mA. Surface roughness measurements were conducted to evaluate the impact of varying the number of passes across 2, 4, 8, and 16 passes. The results indicate that increasing the number of passes leads to a progressive increase in surface roughness. These findings provide valuable insights for optimizing electron beam processing conditions to achieve tailored surface characteristics in titanium-based applications.*

Keywords: *electron beam processing, titanium surface modification, parameter optimization, surfaces roughness, profilometry*

1. INTRODUCTION

Titanium and its alloys have become the materials of choice for biomedical applications, particularly for orthopaedic implants such as artificial hip joints, due to their exceptional biocompatibility, corrosion resistance, low density, and favorable mechanical properties [1], [2]. Among titanium-based materials, Ti-6Al-4V alloy is especially popular for hip implants because of its excellent strength-to-weight ratio, corrosion resistance in physiological environments, and ability to support osseointegration [3]. Furthermore, titanium exhibits a relatively low modulus of elasticity compared to other metallic biomaterials, reducing stress shielding effects and promoting better load transfer to the surrounding bone [4].

Despite these advantageous properties, the clinical success of titanium implants is highly dependent on the surface characteristics of the material. Surface roughness, chemistry, and topography are recognized as critical factors that influence biological responses at the bone-implant interface [5], [6]. In particular, surface roughness plays a pivotal role in modulating cell behaviour, affecting processes such as adhesion, proliferation, differentiation, and ultimately bone tissue ingrowth [7].

Numerous studies have demonstrated that moderately rough surfaces (with average roughness, Ra, between 1 and 2 μm) promote osteoblast differentiation and enhance bone-to-implant contact, compared to either smooth or excessively rough surfaces [8]. Conversely, surfaces that are too smooth may lead to fibrous encapsulation, while surfaces that are too rough can trigger inflammatory responses and increased wear [9]. Moreover, surface roughness affects the mechanical interlocking between the implant and bone, which is essential for achieving primary stability and minimizing micromotion during the early stages of healing [10]. Insufficient primary stability can result in delayed or failed osseointegration, ultimately compromising implant longevity.

Given these critical implications, considerable efforts have been devoted to developing surface modification techniques aimed at optimizing implant surface properties. Conventional methods such as grit blasting, acid etching, anodization, and plasma spraying have been widely applied to modify titanium surfaces [11], [12]. Recently, electron beam processing has emerged as an effective method for surface modification, offering precise control over surface morphology, microstructure, and roughness without introducing chemical contamination [13].

Understanding how electron beam processing parameters, such as the number of passes, influence surface roughness is crucial for designing implants with superior biological performance. Therefore, the present study systematically investigates the effect of the number of passes on the surface roughness of titanium samples processed with a constant beam current of 0.8 mA, providing insights into the optimization of surface treatments for improved clinical outcomes in hip joint replacement applications.

2. MATERIALS AND METHOD

2.1 Material

Commercially available titanium alloy was used for sample preparation. Samples were cut into rectangular shapes with dimensions of 70 mm × 20 mm × 5 mm. Prior to surface modification, the samples were mechanically ground and polished using silicon carbide abrasive paper of P4000 grit to achieve a uniform initial surface finish [14]. After polishing, samples were cleaned with ethanol and dried using compressed air to remove any residual contaminants.

2.2 Electron Beam Surface Treatment

Surface modification was carried out using an electron beam welding device, Probeam EBG 45-150 K14. Each sample contained four distinct treated areas, each measuring 10 mm × 10 mm, subjected to 2, 4, 8, and 16 electron beam passes, respectively (Figure 1).
The electron beam processing was performed with a constant beam current of 0.8 mA.

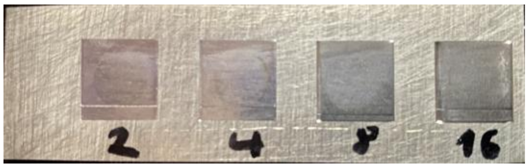

Figure 1. Electron beam processed titanium samples: (a) sample treated with 0.8 mA; (b) sample treated with 1.0 mA

The electron beam processing was conducted at a constant current of 0.8 mA, under an acceleration voltage ranging between 60 and 150 kV, in a high vacuum environment. Raster-scanning of the beam across the designated areas was performed to ensure homogeneous surface modification. All treatments were carried out at room temperature.

2.3 Surface Roughness Measurement

Surface roughness measurements were performed using an INSIZE ISR C-002 profilometer, a portable contact-type instrument designed for precise surface texture characterization. The device operates by moving a diamond-tipped stylus across the sample surface, detecting vertical displacements to generate a surface profile.
Measurements were conducted according to the ISO 4287 standard for surface texture analysis. For each treated area, measurements were performed at three different locations. The surface roughness measurements were

conducted over a measurement length of 4 mm. Surface roughness parameters were recorded.

2.4 Experimental Plan

In this study, titanium samples were processed with a constant electron beam current of 0.8 mA, while the number of beam passes was varied to investigate its effect on surface roughness. Each sample contained four distinct treated areas corresponding to 2, 4, 8, and 16 passes. The experimental matrix is summarized in Table 1.

Table 1. Experimental matrix for electron beam surface modification

Group	Beam Current	Number of Passes
1	0.8 mA	2
2	0.8 mA	4
3	0.8 mA	8
4	0.8 mA	16

3. RESULTS AND DISCUSSION

Surface roughness measurements were performed on titanium samples processed with a constant electron beam current of 0.8 mA and varying numbers of beam passes. The surface roughness profiles obtained from three different locations for each treated area are presented in Figures 2–5. Figure 2 shows the surface roughness profiles for the sample treated with 2 passes, representing Group 1.

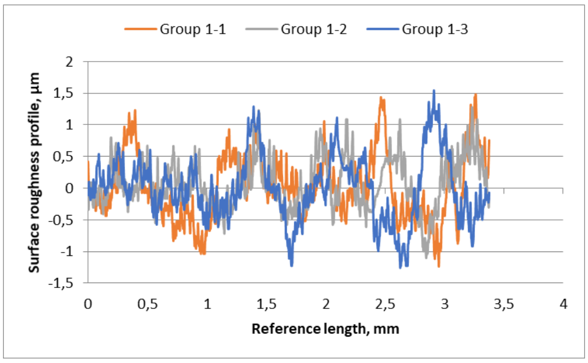

Figure 2. Surface roughness profiles for the sample processed with 2 passes (Group 1) measured at three different locations (Group 1-1, Group 1-2, and Group 1-3)

The surface roughness profiles obtained for the sample processed with 4 passes are presented in Figure 3.

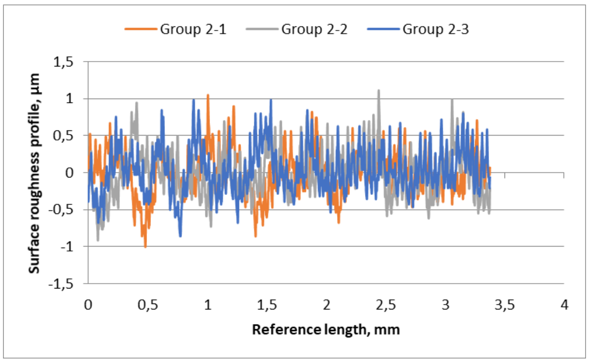

Figure 3. Surface roughness profiles for the sample processed with 4 passes (Group 2) measured at three different locations (Group 2-1, Group 2-2, and Group 2-3)

The surface roughness profiles for the sample processed with 8 passes are shown in Figure 4.

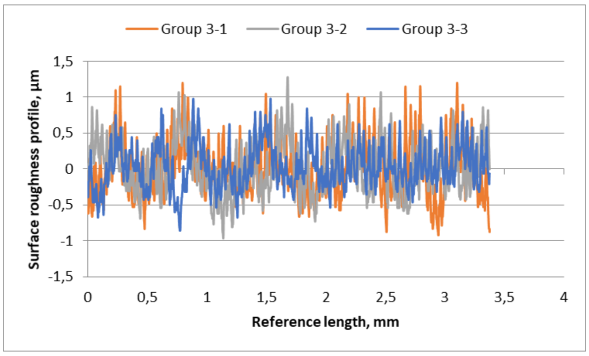

Figure 4. Surface roughness profiles for the sample processed with 8 passes (Group 3) measured at three different locations (Group 3-1, Group 3-2, and Group 3-3)

The surface roughness profiles for the sample processed with 16 passes are presented in Figure 5.

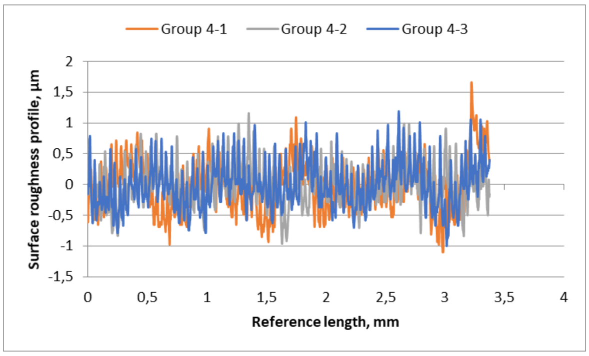

Figure 5. Surface roughness profiles for the sample processed with 16 passes (Group 4) measured at three different locations (Group 4-1, Group 4-2, and Group 4-3)

The average surface roughness values (Ra and Rz) calculated for each group are summarized in Table 2.

Table 2. Average surface roughness values (Ra and Rz) for titanium samples processed with different numbers of electron beam passes at a constant beam current of 0.8 mA

Number of Passes	Average Ra (µm)	Average Rz (µm)
2 passes	0.468	2.631
4 passes	0.311	1.972
8 passes	0.330	2.071
16 passes	0.374	2.358

An initial decrease in Ra and Rz values was observed when increasing the number of passes from 2 to 4. However, further increases in the number of passes (8 and 16) resulted in a slight rise in surface roughness values. This behaviour suggests a non-linear relationship between the number of beam passes and surface roughness.

The results demonstrate that the number of electron beam passes has a significant influence on the surface roughness of titanium samples processed at a constant beam current of 0.8 mA. Initially, increasing the number of passes from 2 to 4 resulted in a noticeable decrease in both Ra and Rz values, indicating a smoother surface. This behaviour can be attributed to the effect of repeated beam scanning, which tends to homogenize the surface by reducing surface asperities created during the first passes.

However, further increasing the number of passes to 8 and 16 led to a slight increase in surface roughness. This trend may be associated with thermal effects, such as localized melting and resolidification, induced by multiple beam exposures. As the number of passes increases, the cumulative heat input can cause microstructural changes, formation of fine surface irregularities, or re-solidified features, leading to a moderate rise in roughness.

Similar non-linear trends in surface roughness evolution with increasing electron beam exposure have been reported in previous studies [13], [14]. The initial smoothing followed by roughening behaviour highlights the need for optimizing the number of passes to balance surface refinement and prevent excessive thermal degradation.

Overall, the findings suggest that an intermediate number of beam passes, particularly 4 passes, provides the lowest surface roughness under the investigated conditions, which could be beneficial for biomedical applications where moderate roughness is desired to enhance osseointegration without promoting excessive wear.

4. CONCLUSION

In this study, the effect of the number of electron beam passes on the surface roughness of titanium samples was systematically investigated at a constant beam current of 0.8 mA. Surface roughness measurements indicated that increasing the number of passes initially reduced surface roughness, achieving the lowest Ra and Rz values at 4 passes. Further increases in the number of passes (8 and 16) led to a moderate rise in roughness, likely due to cumulative thermal effects and surface resolidification phenomena.

The results highlight the importance of optimizing electron beam processing parameters to achieve desired surface characteristics. A moderate number of passes can enhance surface smoothness without introducing excessive thermal damage, which is critical for improving implant performance, particularly in applications requiring enhanced osseointegration and controlled frictional behaviour.

Future work may focus on correlating the observed surface roughness changes with microstructural transformations and biological responses to fully validate the processing conditions for biomedical implant applications.

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REFERENCES

[1] M. Long and H.J. Rack, "Titanium alloys in total joint replacement—a materials science perspective," Biomaterials, vol. 19, no. 18, pp. 1621–1639, 1998, doi: 10.1016/S0142-9612(97)00146-4.
[2] M. Geetha, A.K. Singh, R. Asokamani, and A.K. Gogia, "Ti based biomaterials, the ultimate choice for orthopaedic implants–A review," Progress in Materials Science, vol. 54, no. 3, pp. 397–425, 2009, doi: 10.1016/j.pmatsci.2008.06.004.
[3] M. Niinomi, "Mechanical properties of biomedical titanium alloys," Materials Science and Engineering: A, vol. 243, no. 1–2, pp. 231–236, 1998, doi: 10.1016/S0921-5093(97)00806-X.
[4] M. Navarro et al., "Biomaterials in orthopaedics," Journal of the Royal Society Interface, vol. 5, no. 27, pp. 1137–1158, 2008, doi: 10.1098/rsif.2008.0151.
[5] D.M. Brunette, "The effects of implant surface topography on the behavior of cells," The International Journal of Oral & Maxillofacial Implants, vol. 3, no. 4, pp. 231–246, 1988.
[6] P. Tengvall and I. Lundström, "Physico-chemical considerations of titanium as a biomaterial," Clinical Materials, vol. 9, no. 2, pp. 115–134, 1992, doi: 10.1016/0267-6605(92)90056-Y.
[7] J. Sharan, S. Lale, V. Koul, M. Mishra, and O. Kharbanda, "An overview of surface modifications of titanium and its alloys for biomedical applications," Trends in Biomaterials and Artificial Organs, vol. 29, pp. 176–187, Jan. 2015.
[8] T. Albrektsson and C. Johansson, "Osteoinduction, osteoconduction and osseointegration," European Spine Journal, vol. 10, no. 2, pp. S96–S101, 2001, doi: 10.1007/s005860100282.
[9] J.M. Kienle, L. Diefenbeck, and M. Schmidmaier, "Biomaterials for bone implant coatings," Advanced Drug Delivery Reviews, vol. 94, pp. 280–295, 2015, doi: 10.1016/j.addr.2015.04.013.
[10] G. Szczęsny, M. Kopec, D. J. Politis, Z. L. Kowalewski, A. Łazarski, and T. Szolc, "A Review on Biomaterials for Orthopaedic Surgery and Traumatology: From Past to Present," Materials, vol. 15, no. 10, p. 3622, May 2022, doi: 10.3390/ma15103622.
[11] A. Wennerberg and T. Albrektsson, "Effects of titanium surface topography on bone integration: a systematic review," Clinical Oral Implants Research, vol. 20, no. s4, pp. 172–184, 2009, doi: 10.1111/j.1600-0501.2009.01775.x.
[12] F. Variola, J. B. Brunski, G. Orsini, P. Tambasco De Oliveira, R. Wazen, and A. Nanci, "Nanoscale surface modifications of medically relevant metals: state-of-the art and perspectives," Nanoscale, vol. 3, no. 2, pp. 335–353, 2011, doi: 10.1039/C0NR00485E.
[13] U. Bliznyuk, A. Chernyaev, V. Ipatova, A. Nikitchenko, F. Studenikin, and S. Zolotov, "Electron Beam Processing of Biological Objects and Materials," in Ion Beam Technology and Applications, O. Artun, Ed., IntechOpen, 2023, doi: 10.5772/intechopen.112699.
[14] C. Ramskogler, F. Warchomicka, S. Mostofi, A. Weinberg, C. Sommitsch, "Innovative surface modification of Ti6Al4V alloy by electron beam technique for biomedical application," Materials Science and Engineering: C, vol. 78, pp. 105–113, 2017