Fabrication and characterization of superficially modified porous dental implants

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Abstract

Stress-shielding and loosening compromise the success of dental implants under real-life service conditions. This work evaluates the mechanical behavior of superficially modified porous titanium dental implants fabricated by two different routes: conventional powder metallurgy and space-holder techniques. A novel, feasible and repetitive protocol of micro-milling of the implant thread (before sintering), as well as surface modification treatments (after sintering) are also implemented. The discussion is conducted in terms of the influence of porosity and surface roughness on the stiffness and yield strength of implants. The macro-pores concentrate stress locally, and, at the same time, they could act as a barrier to the propagation of micro-cracks. Higher rugosity was observed for virgin implants obtained with spacer particles. Concerning superficially modified implants, while bioglass 1393 was the most effective coating due to its greater infiltration and adhesion capacity, chemical etching could improve osteoblast adhesion because modifies the roughness of the implant surface.

1. Introduction

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In this work, the influence of the surface modification treatments and the porosity on the mechanical behavior (stiffness and yield strength) are evaluated and discussed on porous dental implants fabricated by both conventional powder metallurgy and space-holder techniques. Novel protocols are proposed to: 1) micro-milled the implant threads and 2) potentially improve the osseointegration (chemical etching and bioactive coating). They were previously optimized by the authors using porous titanium discs [31,32]. These results mean the first steps to achieve our future goal: being able to design a titanium porous dental implant with enhanced biomechanical and biofunctional behavior.

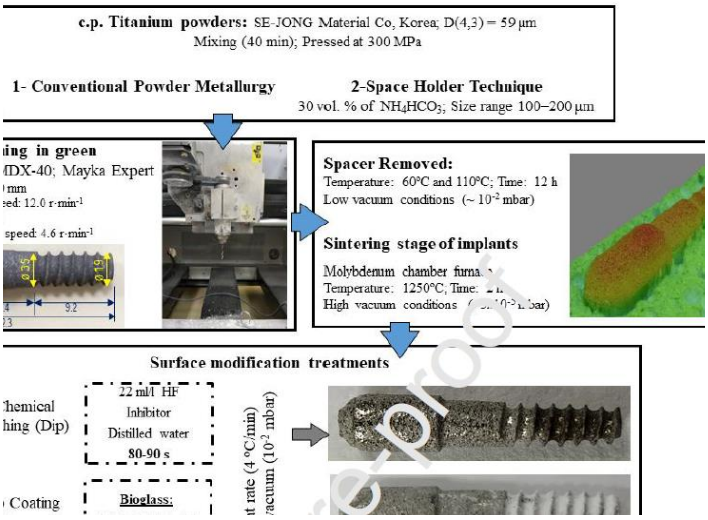
4. Conclusions

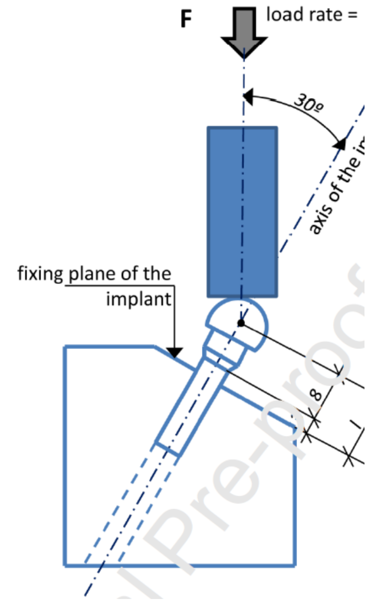
In summary, the results related to the influence of porosity of dental implants manufactured using PM and SH routes, and surface treatments on mechanical behavior allowed indicating:

1) The micro-milling of the implant threads, from green pressed cylindrical preforms obtained by PM and SH routes, was a feasible and repetitive protocol, ensuring the structural integrity and the replica of the design. The surface modification treatments, optimized in previous works (using porous discs), could be also implemented to modify the surface of a real dental implant

2) The roughness of virgin dental implants depends on the percentage of porosity and size of the pores. Roughness values decrease and are more homogeneous in superficially treated implants. With respect to BGs coatings, BG .... is micro-porous while BG .... presents better adhesion and capacity of infiltration in the pores.
3) In general, the results suggested that the pores are preferred sites for nucleation of micro-cracks (stress-concentrators). Furthermore, they act as barriers to the propagation of cracks (blunt their tip), being responsible for the mechanism of increasing fracture toughness (―stop-hole‖ and potential R-curve behavior).
4) Conventional PM porous implants (without surface modification) has a stiffness and elastic limit of .... GPa and .... MPa, respectively. While the .... vol. % SH implants coated with BG ..... presented a better biomechanical (E_d = ..., σ_y = ... MPa, and K_{Ic} = ... MNm$^{-3/2}$) and biofuntional (potential osseointegration) balance, that would allow to guarantee the requirements of cortical bone tissue (E = 20 – 25 GPa, σ_y = 150 – 180 MPa and K_{Ic} = ... MNm$^{-3/2}$).

Figures captions:
Figure 1. Summary scheme of processing of modified surface dental implants.
Figure 2. Scheme of the monotonic test of the porous dental implants.
Figure 3. Optical images of the porosity distribution of implants: a) PM (core) and b) SH (threaded part) routes. Note: micro-pores (in blue and black) and macro-pores inherent to the spacer (colored in red). c) Scheme of the porosity distribution.
Figure 4. Threaded surface profile of the conventional PM dental implants for the thread (left) and the valleys (inset: details of the surface) (right). Note: CLM images at 100x and roughness parameters (S_a and S_q) determined according [37].
Figure 5. SEM (inset: details of the surface) and CLM images of threaded surfaces of dental implants fabricated by SH technique. Note: CLM images at 100x and roughness parameters (S_a and S_q) determined using [37].
Figure 6. Fracture surface under monotonic load test for virgin implant. Influence of the processing routes (PM vs SH). Note the presence of cleavage, mechanism responsible for the fracture.

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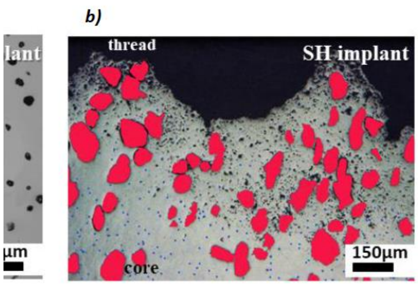
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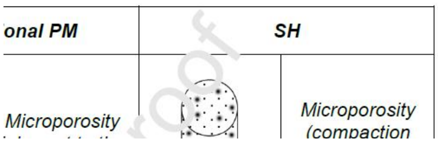
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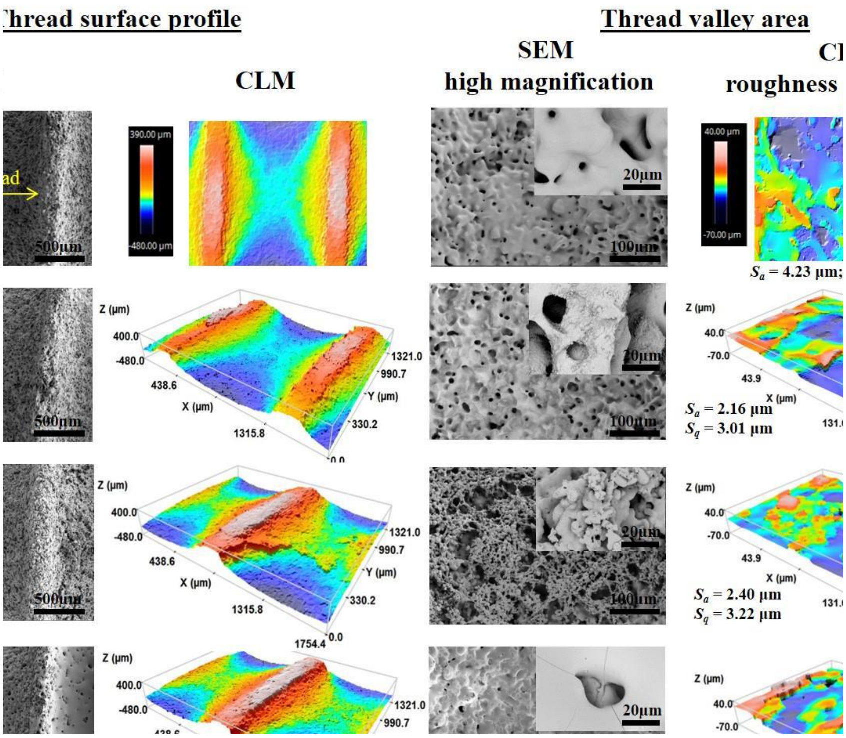
Thread surface profile
Thread valley area
CLM
SEM
high magnification
roughness
500μm
100μm
20μm
S_a = 4.23 μm;
S_a = 2.16 μm
S_q = 3.01 μm
S_a = 2.40 μm
S_q = 3.22 μm