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Titanium surface modified by hydroxyapatite coating for dental implants

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ABSTRACT

The purpose of this study is to obtain a favorable combination of biocompatibility and mechanical properties for dental implants by developing process parameters for plasma-sprayed hydroxyapatite (HA) coating on titanium (Ti-6Al-4V ELI) surfaces. The plasma spraying experiments in this study, involving different process parameters of HA coating (coating thickness up to approximately 120 μm), are divided into four stages. An immersion test for the HA coatings in a simulated body fluid (SBF) was performed after HA coating. After 28 days, the crystallinity level of the HA coatings in the SBF increased from 54.88% to 74.39%, and the released calcium ion concentration increased from 44.9 ppm up to 79.27 ppm. Phase III involved investigating the differences in nozzle transverse speeds and surface speeds between disk- and rod (4.5 mm in diameter)-shaped substrates for plasma HA spraying. The results of Phase III reveal that nozzle transverse speeds of 400 mm/s and titanium surface speeds of 5 rpm may be optimal for the titanium rods. Finally, Phase IV entailed using the parameters alternating from Phase III to perform HA plasma spraying on dental implants measuring 4.5 mm in diameter. An SEM morphology examination indicated that the coverage level of the HA coating was nearly uniform and the thickness was approximately 47–130 μm. This study successfully applied plasma spray technology to an HA spray for titanium surface modification. The evaluation and characterization of the resulting HA coatings reveal that the Phase IV parameters may be used for HA-coating on titanium dental implants. The coatings contained no significant phase components such as tricalcium phosphate (α-TCP, β-TCP) or tetracalcium phosphate (TTCP).

1. Introduction

Previous studies have explored the surface modification of titanium dental implants for many years. Based on a study on titanium biocompatibility conducted by Branemark in 1951 [1], titanium alloys have become main materials for dental implants. Surface modification can lead to favorable bone regeneration and integrity between the bone tissue and implant surface. This technique not only retains the original biocompatibility of titanium alloys, but also improves the clinical performance of dental implants. Previous studies have recently proposed numerous surface treatment methods, including sandblasting, acid etching, electrochemical treatment, and thermal spray coating [2–4]. Using the aforementioned surface modification techniques for commercial dental implant products makes achieving most mechanical requirements and biocompatible properties possible.

Surface treatment is critical for dental implants. Among the implant surface treatment technologies in the dental implant market, SLA (sandblasting with large grit and acid etching) [5–9] is currently the main method. Hydroxyapatite ($Ca_{10}(PO_4)_6(OH)_2$, i.e., HA) is a calcium phosphate bio-ceramic material with nearly the same chemical composition as human bone, and has remarkably high biocompatibility and can be used to guide bone regeneration [10]. Accordingly, plasma-sprayed HA coating [4] is a promising method for enhancing the performance of dental implants.

The power of plasma is determined according to the product of current and voltage; therefore, the current is proportional to the power. The range of the current of a typical plasma-sprayed HA coating is approximately between 350 and 1000 A [11]. Cizek et al. [12] demonstrated that high-power plasma spraying could elevate the temperature of a flame and improve the degree of particle melting. Additionally, with an accelerated flame and an increase of net power by 10 kW, the particle temperature can increase by 80 °C and the speed reaches 60 m/s. Guessasma [13] indicated that the temperature of particles increased from 230 ± 272 °C to 263 ± 168 °C, and the speed of particles increased from 221 ± 34 m/s to 324 ± 46 m/s as the current increased from 350 to 750 A. Therefore, as the current for plasma spray increases, both the temperature and speed of particles increase accordingly.

Quek [11], Tsui [14], Sun [15], and Yang [16] have investigated the effect of the power of plasma spray and current on HA coating. Tsui [14] and Sun [15] have stated that increased power or current leads to

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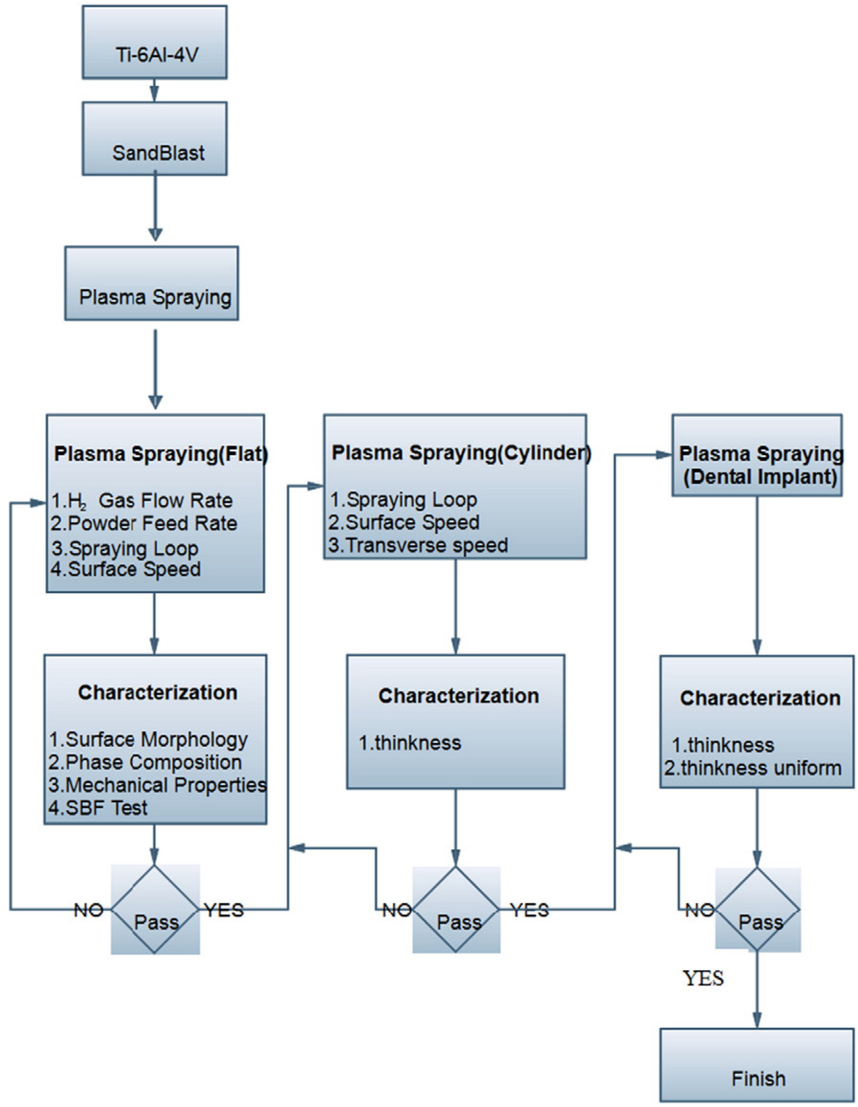

Fig. 1. Flowchart of the study procedure.

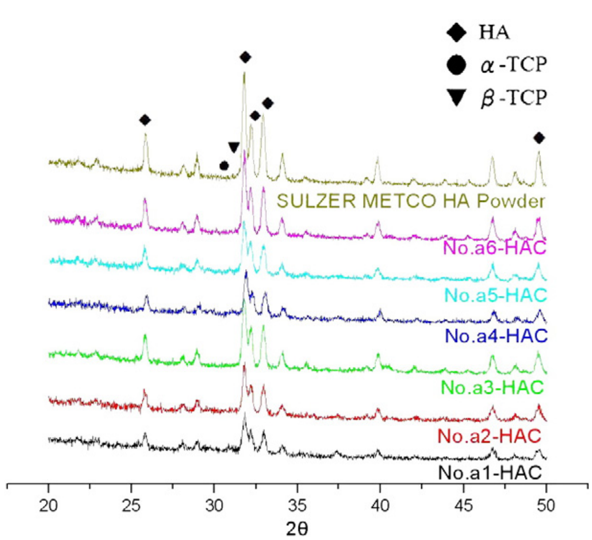

Fig. 2. X-ray diffraction pattern of SULZER METCO powder and HA coatings on Ti-6Al-4V ELI disks.

a decreased degree of crystallization on HA coatings. Tsui [14] also proposed that an increase in the power of plasma spray reduces the porosity and length of microfissures. However, Yang [16] claimed that an increase of current in plasma spray enhances the HA degree of crystallization.

Quek [11] indicated that the faster the lateral displacement of the plasma flame is, the higher the porosity, the lower the degree of crystallization, and the stronger the binding strength. Sun [15] investigated the effectiveness of spraying distances of 8 to 16 cm, and determined that, as the spraying distance increased both the degree of crystallization and the hydroxyl content in HA reduced, resulting in an increase in porosity and number of fractures. Kweh [17] demonstrated that an increase in the spraying distance reduces the mechanical property of the coating. The authors have found that the porosity and amount of powder that have not melted have increased. In addition, an inhomogeneous deposition has formed at spraying distances between 12 and 14 cm, and that coatings with the optimal mechanical property have been obtained at a spraying distance of 10 cm.

Taylor [18] revealed that certain materials, such as carbites, are not suitable for hydrogen gas coating, because hydrogen gas reacts with coating materials. Guessasma [13] proposed that increasing gas flow