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Surface Integrity and Corrosion Performance of Biomedical Magnesium-Calcium Alloy Processed by Hybrid Dry Cutting-Finish Burnishing

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Abstract

Biodegradable magnesium-calcium (MgCa) alloy is a very attractive orthopedic biomaterial compared to permanent metallic alloys. However, the critical issue is that MgCa alloy corrodes too fast in the human organism. Compared to dry cutting, the synergistic dry cutting-finish burnishing can significantly improve corrosion performance of MgCa0.8 (wt %) alloy by producing a superior surface integrity including good surface finish, high compressive hook-shaped residual stress profile, extended strain hardening in subsurface, and little change of grain size. The measured polarization curves, surface micrographs, and element distributions of the corroded surfaces by burnishing show an increasing and uniform corrosion resistance to simulated body fluid.

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Keywords: Surface Integrity; Biomedical; Corrosion; Biodegradable Implant; Hybrid Manufacturing

1. Introduction

Biodegradable magnesium-calcium (MgCa) alloys have potentials to minimize stress shielding and avoid surgical interventions inherited in conventional permanent orthopedic implants made of stainless steel, titanium, and cobalt-chromium alloys [1]. However, the critical challenge for an MgCa implant is that it has poor corrosion resistance in

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the environment of the human organism. Therefore, how to adjust the corrosion performance of an MgCa implant is a critical technical barrier to realize its great socioeconomic benefits.

The excellent machinability of Mg alloys enables high speed dry cutting to be an ecological-friendly and economical process due to the elimination of cutting fluids [2, 3]. Dry cutting of Mg alloys with PCD tools produces good surface finish and hardened surface by the combination of high cutting speeds and low feeds in face milling of Mg alloys [4, 5]. In contrast high speed machining (HSM) for extended cutting time at high speeds may promote the formation of flank build-up (FBU) which leads to low surface finish [2, 3, 6] . Low magnitudes and shallow depths of compressive normal residual stress were measured by x-ray diffraction with Cu/Ni source and high Bragg angle of 118.6o for the dry turned MgCa3.0 (wt% Ca) surfaces at low cutting speeds (10-100 m/min) [1]. Relatively high compressive principal residual stresses at the milled MgCa0.8 surfaces at high cutting speeds (1200-2800 m/min) were measured by Co x-ray source and low Bragg angle of 42.89° [5]. However, the measured magnitudes of residual stresses for the turned MgCa3.0 surfaces and milled MgCa0.8 are not comparable due to their different nature and measuring conditions.

Due to the limitation of dry cutting to produce superior surface integrity, rolling/burnishing has been used as an alternative process to enhance surface integrity [7]. Deep rolling has been shown to improve surface finish of various Mg alloys [1, 4, 6, 8]. Surface hardness and compressive residual stress in the subsurface of Mg AZ91 alloy can be produced if adequate burnishing conditions have been chosen [8]. Compressive residual stresses at the surface and in the subsurface of MgCa3.0 alloy were also measured [1]. However, a significant modification of microhardness in correlation to the residual stress state was not detected for the burnished MgCa3.0 alloy. The increase of rolling force reduces the magnitudes of compressive residual stress at the surface but shift the maximum compressive residual stress into the deep subsurface. High rolling force may deteriorate surface finish and induce subsurface cracks [8].

It has been shown that lower surface roughness caused higher corrosion rate in the salt spray test of machined Mg WE43 surfaces [4] and the in-vivo test of sandblasted MgCa0.8 surfaces [9]. Furthermore, lower surface roughness did not show a significant influence on corrosion performance of turned MgCa3.0 surfaces in solution of 0.9 wt% NaCl. However, the high compressive residual stresses in the subsurface via deep rolling reduced the corrosion rate by a factor of about 100 [1]. Nevertheless, the effects of surface integrity of MgCa0.8 alloy processed by HSM and burnishing on corrosion performance in a simulated body fluid (SBF) have yet to be studied.

The objectives of this study are to: (a) produce and characterize superior surface integrity of MgCa0.8 alloy by synergistic dry cutting-finish burnishing; (b) study how surface integrity affect the spontaneity and kinetics of the processed surfaces in SBF medium via the potentiodynamic technique; (c) characterize micrographs and chemical compositions of the corroded surfaces; and (4) determine whether the literature results are transferable to MgCa0.8 alloy.

2. Surface integrity by synergistic dry cutting-burnishing

2.1. Experimental setup and conditions

Binary Mg-Ca0.8 alloy was prepared in a crucible using pure Mg of the ASTM grade 9980A and Mg-30% Ca master alloy [9]. Experimental setup of the synergistic cutting-burnishing is shown in Figure 1. A broad range of cutting speeds and rolling forces in Table 1 was used to investigate the effects of process parameters on surface integrity. Poly crystalline diamond (PCD) inserts were utilized in high speed face milling to take advantage of low chemical affinity and friction between Mg and diamond in dry cutting process. High pressure hydraulic unit in provides a pressurized hydro cushion for the silicon nitride ceramic ball (dia. 12.7 mm) at the tip of the burnishing tool. This avoids the contact between ball and spherical housing and guarantees free rolling along the sample surface. The power carrying fluid is anti-wear, dual purpose Aries 15 oil functioning as both coolant and lubricant. Cylindrical MgCa0.8 bars of 50 mm diameter were prepared into two categories: surfaces of type (I) cut by dry HSM and surfaces of type (II) cut by dry HSM and then rolled by finish burnishing. The type I surfaces are used as baseline to benchmark process capability of the synergistic cutting-burnishing. The synergistic cutting-burnishing utilizes different physical principles involved in material removal and forming processes. Each physical principle produces distinct attributes of surface integrity. For example, the depth of compressive residual stress in the