Wear 376-377 (2017) 243–250

Contents lists available at ScienceDirect

Wear

journal homepage: www.elsevier.com/locate/wear

Biotribological study of multi-nano-layers as a coating for total hip prostheses

A.V. Garza-Maldonado [a], M.A.L. Hernandez-Rodriguez [a,*], M. Alvarez-Vera [a,b], J.A. Ortega-Saenz [c], A. Perez-Unzueta [a], R. Cue-Sampedro [d]

[a] Universidad Autonoma de Nuevo Leon, FIME, Mexico
[b] Corporacion Mexicana de Investigacion en Materiales SA de CV, Mexico
[c] Mechanical Engineering Department, The University of Texas Rio Grande Valley, 1201 West University Drive, Edinburg, TX 78539, United States
[d] Tecnologico de Monterrey, Campus Monterrey, Mexico

ARTICLE INFO

Article history:
Received 10 September 2016
Received in revised form
17 December 2016
Accepted 27 December 2016

Keywords:
Hip joint simulator
Metal-on-metal
PVD
Multi-nano-layers coating
CrN/TiN
Boron addition

ABSTRACT

Metal-on-metal (MOM) hip joint bearings have demonstrated low wear rates. However, wear of MOM joints is a concern due to the toxicity and biological reaction of wear debris and dissolution by metallic corrosion. There is, therefore, considerable interest in further reducing the wear of MOM bearings for hip prostheses. The aim of the present study was to investigate the wear properties of surface engineered CoCr cast metal-on-metal hip prostheses. For this purpose, a nano-layer coating system (TiN/CrN) $\times$ 25 $\approx$ 1 μm was prepared by physical vapor deposition (PVD) for the femoral heads. On the other hand, the acetabular cups were treated by PVD obtaining a coating of CrN $\approx$ 4 μm. The femoral heads were tested against the acetabular cups using a three-axial multi-station hip joint simulator. During the wear tests three directions of motion were applied with the following amplitudes: flexion–extension (FE) $\pm 23°$, abduction–adduction (AA) $\pm 23°$ and internal–external rotation (IER) $\pm 8°$. All components were undertaken at 1.2 Hz under a single axis loading pattern with a maximum load peak of 2 kN and bovine calf serum solution as lubricant. Surface damage analysis performed by scanning electron microscopy (SEM) and energy disperse spectroscopy (EDS) showed the wear mechanisms involved during wear tests. Mild adhesion and delamination between the multilayers of contact sections of the surface were evidenced. However, at 2 million cycles, the metal matrix was not worn resulting in a significant improvement of the wear resistance.

1. Introduction

Wear is considered one of the main concerns in hip replacements, not only for the most used metal-on-polyethylene (MOP) implants, but also for the new generation of metal-on-metal (MOM) couplings [1]. The use of MOM hip resurfacing arthroplasty is currently an option for younger patients needing a hip arthroplasty or to treat end-stage arthritis [2]. However, in recent years, concerns have been raised about the toxicological implications of particles generated from the wear of MOM hip implants [3].

Several studies of hip replacements with microstructure and surface modifications to improve the tribological behavior have been reported in the last years. It has been reported that boron addition in Co–Cr alloy increases the wear resistance due to the formation of interdendritic net of complex boron carbides which are more resistant to the abrasion mechanism [4]. On the other hand, various studies have reported that deposition of CrN and TiN hard coatings on hip replacements improve the wear resistance. In this regard, Galvin [5] studied the effect of femoral heads coated with CrN using arc evaporative physical vapor deposition showing scratch resistance comparable to an alumina head. Villiers [6] also investigated the influence of large diameter metal-on-polyethylene bearings coated with CrN using an electron beam physical vapor deposition resulting in a reduced generation of nano-sized polyethylene particles. Łapaj [7] performed a retrieval analysis of femoral heads coated with TiN using cathodic arc physical vapor deposition indicating that coated implants are less susceptible to wear. Ortega [8] studied the tribological behavior of femoral heads coated with a TiN/CrN multilayer coating created by plasma assisted physical vapor deposition, demonstrating an improvement in the wear resistance when compared against uncoated MOMs. Meanwhile, Sahasrabudhe [9] performed studies using commercially pure titanium remelting the surface by means of focused laser radiation in a nitrogen rich inert atmosphere to form in situ TiN/Ti coating showing higher hardness and wear resistance.

CrN/TiN superlattice produced by magnetron sputtering has been used as multilayer coating due to its excellent mechanical

* Corresponding author.
E-mail address: malhdz@gmail.com (M.A.L. Hernandez-Rodriguez).

http://dx.doi.org/10.1016/j.wear.2016.12.043
0043-1648/

Table 1
The chemical composition (wt%) of the samples.

Element	ASTM F-75 alloy (Co–Cr)	ASTM F-75+1 wt% B alloy (Co–Cr+B)
Co	Bal.	Bal.
Cr	29.32	28.33
Mo	5.91	5.35
Ni	0.192	0.238
Fe	0.238	0.184
C	0.23	0.26
Si	0.28	0.63
Mn	0.43	0.46
W	0.15	0.13
P	0.013	0.012
S	0.008	0.006
N	0.09	0.16
Al	0.08	0.03
Ti	0.01	0.03
B	**0.003**	**0.98**

properties, and its high wear and corrosion resistance [10–14]. In a previous study, TiN/CrN superlattices were deposited on two different types of substrates: cast Co–Cr (ASTM F75) and cast Co–Cr+1 wt% B alloys. After ball-on-disc wear testing, an enhancement on the tribological properties of the substrates with boron content was evidenced due to a massive secondary phase precipitation [15].

The main aim of the present study was to evaluate the tribological behavior of metallic femoral heads surface modified with TiN/CrN multi-nano-layers superlattice coating articulating against CrN coated metallic acetabular cups in an anatomical hip joint simulator. Femoral heads and cups were produced using two different alloys: Co–Cr (ASTM F75) and Co–Cr+B (Co–Cr+1 wt% B).

2. Materials and methods

2.1. Metal-on-metal bearings

Eight MOM couplings (cup and head implants) of 38 mm in diameter with different boron contents were manufactured using the investment casting method. For this purpose, electrolytic metals (Co, Cr, Mo, C, and B) were melted using an induction furnace. The analysis of the chemical composition of the cast Co–Cr alloy while varying the boron content are given in Table 1. The samples with 0.003 and 0.98 wt% boron correspond to samples ASTM F-75 (Co–Cr) and ASTM F-75+1 wt% B (Co–Cr+B) respectively.

2.2. Coating deposition

After mirror like polishing, the MOM cup and head implants were cleaned by immersion using an ultrasonic bath of acetone for 5 min. A PVD magnetron sputtering system, V1 Intercovamex, was used to create the coatings. Prior to deposition, the vacuum chamber was pumped down to 3×10^{-3} Torr. Currents of 0.27 A and 0.34 A were used for Ti and Cr cathodes respectively. A bias voltage of 456 V and 318 V was used for the Ti and Cr substrates

Table 3
Mean dimensions of the head and cup components.

Sample	Mean diametral clearance C_d (μm)	Mean roughness R_a (nm)	Mean sphericity (μm)
Co–Cr (n=4)	102–106	14.5	1.925
Co–Cr+B (n=4)	92–95	20.5	2.905

Fig. 1. Hip joint simulator FIME II [17].

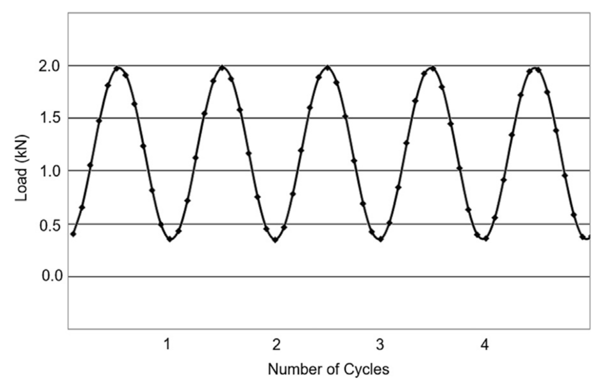

Fig. 2. Load pattern followed by the FIME II hip simulator [17].

Table 2
Parameters of PVD processes.

Sample	Temperature (°C)	Pressure (Torr)	Coating
Heads			
Co–Cr n=2	448	6.65×10^{-3}	Superlattice:TiSiN-ML ≈ 3 μm+TiN/CrN × 25 ≈ 1 μm
Co–Cr n=2			Uncoated
Co–Cr+B n=2	450	67.6×10^{-3}	Superlattice:TiSiN-ML ≈ 3 μm+TiN/CrN × 25 ≈ 1 μm
Co–Cr+B n=2			Uncoated
Cups			
Co–Cr n=2	450	7.2×10^{-3}	TiSiN-ML ≈ 3 μm+CrN ≈ 4 μm
Co–Cr n=2			Uncoated
Co–Cr+B n=2	450	7.2×10^{-3}	TiSiN-ML ≈ 3 μm+CrN ≈ 4 μm
Co–Cr+B n=2			Uncoated