Measurement 54 (2014) 249–255

Contents lists available at ScienceDirect

Measurement

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

Modelling and optimization of biotribological testing parameters on frictional heating of vitamin E blended UHMWPE with the help of statistical techniques

Binnur Sagbas [a,*], M. Numan Durakbasa [b]

[a] Yildiz Technical University, Department of Mechanical Engineering, 34349 Besiktas, İstanbul, Turkiye
[b] Vienna University of Technology, Department of Interchangeable Manufacturing and Industrial Metrology, Karlsplatz 13/3113, A-1040 Wien, Austria

ARTICLE INFO

Article history:
Available online 27 January 2014

Keywords:
Vitamin E blended UHMWPE
Hip joints
Frictional heating
Frictional temperature
Surface dimple

ABSTRACT

It is known from previous studies that frictional temperature rise on the surfaces of artificial joints could reach high levels that make hazardous effects on surrounding tissue and lubricant around the artificial joint. For enhancement the tribological behavior of the joints, new material combinations have been tried. In this study vitamin E blended ultra-high molecular weight polyethylene (VE-UHMWPE), which is one of the new generation material, was used for acetabular inserts. These inserts were paired with CoCrMo femoral heads. For reduction of the frictional heating, testing parameters and their effects were investigated by using Taguchi method and analysis of variance. The results were analyzed by using Statistical Package for Social Science (SPSS 15.0). Also mathematical model for the temperature rise (ΔT) was developed with the help of statistical techniques.

In vitro frictional heating measurements were carried out on a custom made hip joint friction experimental set-up. 0.3–0.5 mm in diameter surface dimples were machined on the inner surface of acetabular insert samples. Different static loads, representing different body weights, were applied with different walking duration. Bovine calf serum was used as lubricant and different amount of bone cement (PMMA) was added in the lubricant as third body abrasive particles. Temperature rises were recorded with embedded thermocouples. The experimental results demonstrated that the surface dimples were the major factor on frictional heating, followed by applied load, amount of third body particles and time.

1. Introduction

Previous measurements of frictional temperature rise on the surfaces of artificial joints have shown that temperature values could reach high levels that make hazardous effects on surrounding tissue and lubricant around the artificial joint [1–3]. In vivo measurement study, Bergmann et al. recorded 43.1 °C temperature rise on the surface of hip prosthesis after 1 h walking [4]. In [3] Lu and McKellop measured the temperature for UHMWPE acetabular insert as 40.4 °C under 2030 N loading and 6 h test duration in vitro conditions. It is reported that if temperature rise reaches to 40 °C, formation of fibrous tissue may occur around the hip joint and this can induce periprosthetic pain and at the end failure of prosthesis [1,5]. For improvement tribological properties of conventional UHMWPE radiation-induced cross linking process was applied. The wear resistance was increased by cross-linking but oxidation resistance and mechanical properties were decreased because of the thermal treatments applied after the cross-linking process [6–9]. For reducing the problems aroused by the post-irradiation thermal treatment,

* Corresponding author. Tel.: +90 216 383 28 06; fax: +90 212 261 66 59.
E-mail addresses: bsagbas@gmail.com (B. Sagbas), aum@mail.ift.tuwien.ac.at (M.N. Durakbasa).

http://dx.doi.org/10.1016/j.measurement.2014.01.022
0263-2241/

α-tocopherol or vitamin E has been added in to the structure of UHMWPE as a natural antioxidant [10]. In previous studies it was reported that addition of vitamin E increases oxidation and delamination resistance of UHMWPE [11–13].

Besides materials structural properties, surface properties and lubrication of the sliding surfaces are also very important factors for reduction of frictional heating. Surface patterning is an effective method for obtaining better lubrication condition [14–17]. Ito et al. formed concave dimples on CoCr alloy femoral head and they reported that surface dimples were served reduction abrasive wear of UHMWPE insert [18]. In another study Zhang et al. formed micro dimples on conventional UHMWPE disc samples and they concluded that wear and friction of UHMWPE decreased with surface dimples [14].

Previous studies focused on effect of surface dimples on wear and friction coefficient of conventional UHMWPE. Little literature research is available about frictional heating of VE-UHMWPE, actually there is no temperature rise measurement study about surface patterned VE-UHMWPE acetabular insert except our previous studies [19,20]. In our previous studies [19,21] we studied on frictional heating of 0.5 mm in diameter surface dimpled conventional UHMWPE and VE-UHMWPE. In [20] the effect of frictional heating parameters such as different dimple diameters, amounts of PMMA, applied load and walking time was reported and the optimal test parameters were determined. In this study, besides optimization of the frictional heating parameters by Taguchi approach, the results were analyzed by statistical techniques. Also mathematical model for the temperature rise, (ΔT) as a function of dimple diameter, amount of third body particles PMMA, applied load and testing duration was developed with the help of regression analysis.

2. Materials and methods

Acetabular inserts were machined from Chirulen 1020 E rods (MediTECH Medical Polymers, Vreden, Germany). The inner surface of the samples were machined same as an acetabular insert and in accordance with ISO 7206-2:2011 and ISO 21535 [22,23]. To provide uniform construction for heat dissipation, metal backing or fixing tools were not used except screw to fix the samples. For this reason the outer surfaces of the samples were cylindrical in 40 mm diameter and three screws were used for fixation. Acetabular insert samples were divided in three groups. First group stayed as machined. 0.3–0.5 mm in diameter surface dimples were machined on second and third group's surfaces by five axis computer numerical control milling machine. Depth of the dimples were 0.5 mm. The distance between the center of the 0.3 mm in diameter dimples were 1.5 mm and the distance between the center of the 0.5 mm in diameter dimples were 2 mm. Surface roughness measurements of the samples and microscopic evaluation of the dimples was carried out in Vienna University of Technology, Interchangeable Manufacturing and Industrial Metrology, Nanometrology Laboratory. CAD/CAM model of acetabular insert (a), manufactured acetabular insert sample (b), and microscopic image of 0.5 mm in diameter surface dimple (c) can be seen in Fig. 1.

The acetabular insert samples were paired with CoCrMo commercially available femoral heads. The prostheses were in 28 mm diameter. Surface roughness of acetabular inserts was measured by Taylor Hobson Form Talysurf Intra. The average surface roughness of vitamin E blended UHMWPE (VE-UHMWPE) was 0.647 μm. This value is suitable for the reference of ISO 7206-2:2011 [22]. Mechanical and thermal properties of VE-UHMWPE and CoCrMo can be seen in Table 1.

Frictional measurements of the joints were carried out on a custom made hip joint friction simulator. For elimi-

Table 1
Mechanical and thermal properties of VE-UHMWPE and CoCrMo.

Variable	Unit	VE-UHMWPE Average	CoCrMo Average
Density	kg/m^3	937	8270
Young's modulus	MPa	683	200
Poisson's ratio	–	0.46	0.3
Thermal conductivity	W/(m K)	0.4	12.1

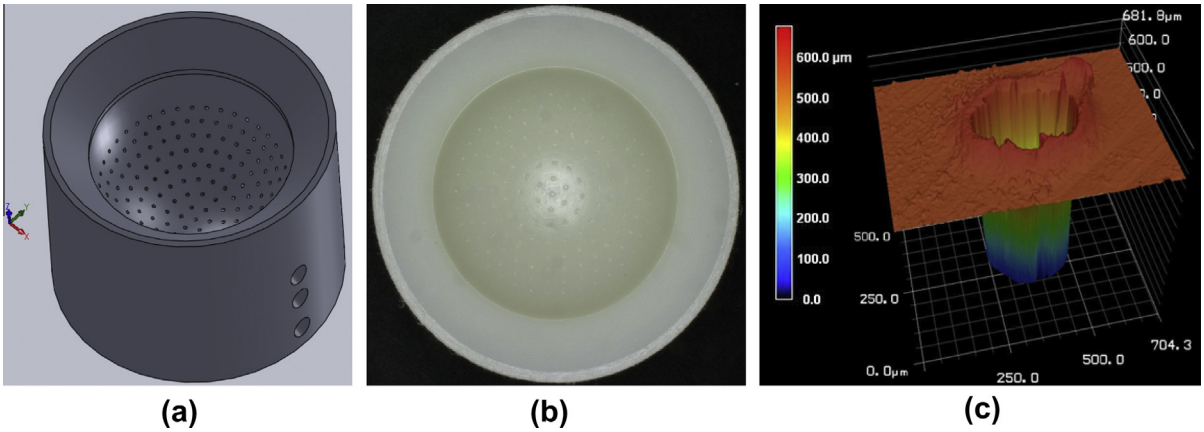

Fig. 1. (a) 3D CAD model of the acetabular insert with surface dimples and thermocouple holes. (b) Manufactured acetabular insert. (c) Microscopic image of 0.5 mm in diameter dimple.