Precision Engineering 33 (2009) 492–498

Contents lists available at ScienceDirect

Precision Engineering

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

Study on long life of artificial joints by investigating optimal sliding surface geometry for improvement in wear resistance

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A R T I C L E I N F O

Article history:
Received 21 August 2008
Received in revised form 9 December 2008
Accepted 31 January 2009
Available online 26 March 2009

Keywords:
Effective life of artificial joint
Sliding surface
Dimple structure
Wear resistance
Scratch marks
Abrasive waterjet

A B S T R A C T

The effective life of artificial joints is approximately 15 years. A smooth metal sliding surface is presumably the most suitable when manufacturing artificial joints; however, the relationship between the characteristics of metal sliding surface and ultra high molecular polyethylene (UHMWPE) wear has not been confirmed. Further, there is no apparent proof that a smooth surface is the optimal option for the improvement in the wear resistance of artificial joints. In this study, we investigated the mechanism of UHMWPE wear and proved that scratch marks caused by a sliding motion against the metal surface are the prime cause of UHMWPE wear. Furthermore, we used a micro-dimpled surface as an effective sliding surface to reduce the UHMWPE wear. A 2-axes pin-on-plate sliding test proved that the life of artificial joints can be extended to approximately 35 years by using a micro-dimpled surface with 1-μm deep dimples.

1. Introduction

Joint replacements are provided to patients whose joints are damaged by articular rheumatism or coxarthrosis, and they play a very important role in social rehabilitation. However, the effective life of an artificial joint is limited to approximately 15 years. The primary factor behind the limitation in the effective life is the destruction of UHMWPE (ultra high molecular polyethylene) components that function as cartilage. It is not only known that the destruction of the UHMWPE components due to wear leads to functional deterioration as a joint but also a wear powder thus discharged stimulates osteoclast and loosens the fixed portion of the artificial joint (Fig. 1) [1–3]. If an artificial joint loosens, it must be replaced; therefore, UHMWPE wear must be reduced in order to improve the life of artificial joints.

Conventionally, a smooth metal surface is utilized when manufacturing artificial joints. However, it is uncertain whether the smooth surface is the most favorable option to improve the wear resistance of artificial joints because the relationship between the characteristics of the metal sliding surface and the UHMWPE wear has not been confirmed. Therefore, it is essential to investigate this relationship for the improvement in the effective life of artificial joints.

The purpose of this study is to improve the life of artificial joints to more than 30 years and develop artificial joints with the most effective sliding surface to reduce the friction of UHMWPE. Furthermore, in this study, we investigated the relationship between the characteristics of the sliding surface and the UHMWPE wear by conducting a 2-axes pin-on-plate sliding test.

2. Sliding surface with wear resistance to prolong the effective life of artificial joints

2.1. Investigation of the mechanism of wear of artificial joints

Scratch marks were observed on the sliding surface of an artificial hip joint that had loosened and had been removed from a live human being [4]. Hence, we believe that the scratch marks on the sliding surface of the metal are the main cause of the UHMWPE wear. Next, we assume that the mechanism of the wear of the artificial joint is as follows (Fig. 2).

(a) Scratch marks occur on the sliding surface of the metal component by external particles or wear particles.
(b) These scratch marks cut into the UHMWPE surface, and the wear rate of the UHMWPE increases.

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0141-6359/$ – see front matter
doi:10.1016/j.precisioneng.2009.01.005

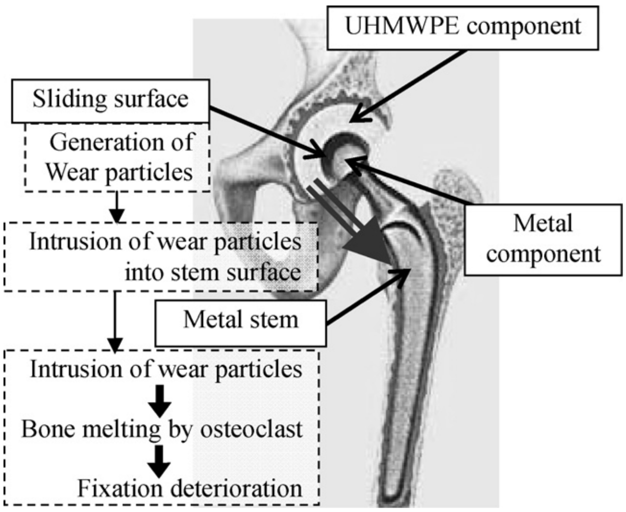

Fig. 1. Influence of UHMWPE wear on artificial joint.

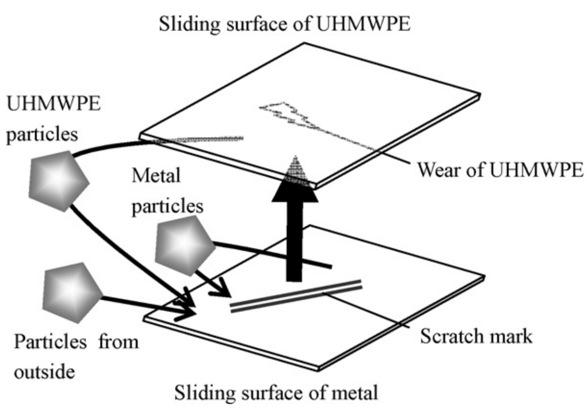

Fig. 2. Mechanism of wear on sliding surface of artificial joint.

2.2. Proposal of an optimal sliding surface to improve the wear resistance

From the discussion in the previous section, it is understood that scratch marks should be prevented to reduce the UHMWPE wear. In this study, we suggest forming micro-dimples on the metal surface to increase the wear resistance. By using the micro-dimpled surface, scratch marks on the sliding surface can be prevented because particles on the sliding surface get trapped within the dimples, as shown in Fig. 3. With no scratch marks on the metal surface, the wear resistance can be increased, and it is possible to prolong the life of the artificial joint.

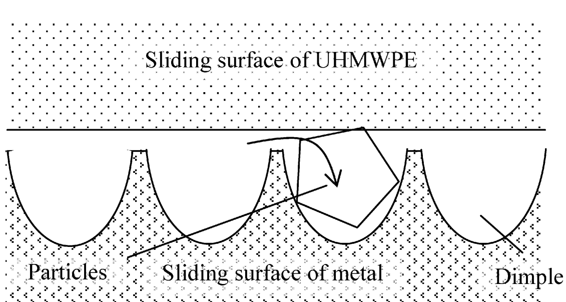

Fig. 3. Reducing scratch marks by formation of dimples.

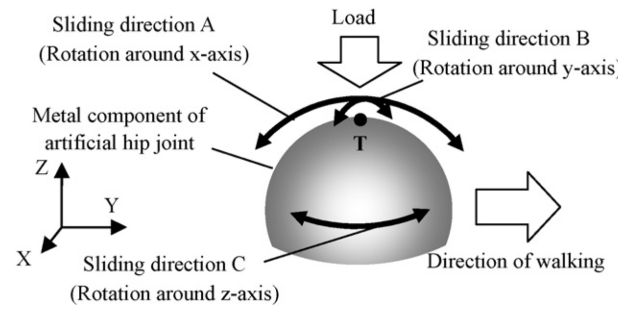

Fig. 4. Experimental model of hip joint simulator.

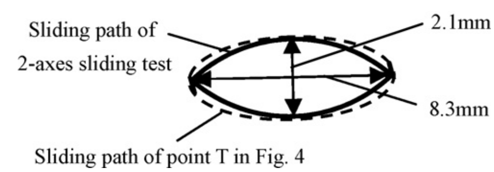

Fig. 5. Sliding path in 2-axes sliding test.

3. Sliding test to examine an optimal sliding surface to improve the wear resistance

3.1. Experimental method

The 2-axes pin-on-plate sliding test was conducted to examine the relationship between the characteristics of the sliding surface and the UHMWPE wear. In this test, UHMWPE pins and Co–Cr–Mo alloy plates were used as experimental samples. The sliding path was determined on the basis of the sliding test conducted on a hip simulator specified in the standard ISO 14242-1 [5]. According to the standard ISO, the sliding motion of a UHMWPE component against a metal component is a 3-axes rotation, as shown in Fig. 4. The rotation angles were 43° around the x-axis, 11° around the y-axis, and 12° around the z-axis. The sliding frequency was set as 1 Hz.

In this study, by assuming that the rotation around the z-axis can be ignored while walking, the sliding motion corresponding to the rotations around the x- and y-axes has been considered. The projection of the path of point T in Fig. 4 during the rotations around x- and y-axes with respect to the xy-plane takes the form of an ellipse, as shown in Fig. 5. On basis of this elliptical form, a sliding path with two arcs as shown in Fig. 5 has been used in the experiment.

The number of sliding cycles while walking over a period of 3 months was 0.25×10^6. The experimental conditions are presented in Table 1.

3.2. Preparation of the experimental samples

UHMWPE pins whose sliding surfaces were prepared by a cutting process were used as pin samples, and Co–Cr–Mo alloy plates with mirrored surfaces and dimpled surfaces were used as plate samples.

An abrasive waterjet was applied for the formation of dimples on the plate samples. The injection method employed for creating the

Table 1
Experimental conditions.

Diameter of sliding surface [mm]	6.0
Load [N]	147
Sliding speed [mm/s]	18.7
Number of sliding cycles	0.25×10^6
Lubricating liquid	Water