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Editor's comment: The paper by Baxmann et al. concerns total hip arthroplasty components, specifically titanium alloy neck adapters, which are at risk of failure owing to fretting and crevice corrosion. The authors developed an experimental apparatus for the purpose of simulating the effect of micromotion and contact pressure at the taper interface of modular hip prostheses under physiological conditions. Evaluations of this kind are essential if taper designs and materials that are less susceptible to this mode of failure are to be developed.

Richard Black, Editor-in-Chief

The influence of contact conditions and micromotions on the fretting behavior of modular titanium alloy taper connections

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ABSTRACT

Modularity of femoral stems and neck components has become a more frequently used tool for an optimized restoration of the hip joint center and improvement of patient biomechanics. The additional taper interface increases the risk of mechanical failure due to fretting and crevice corrosion. Several failures of titanium alloy neck adapters have been documented in case-reports.

An experimental fretting device was developed in this study to systematically investigate the effect of micromotion and contact pressure on fretting damage in contact situations similar to taper interfaces of modular hip prostheses under cyclic loading representative of in vivo load conditions. As a first application, the fretting behavior of Ti–6Al–4V titanium alloy components was investigated. Micromotions were varied between 10 μm and 50 μm, maximum contact pressures between 400 and 860 N/mm^2. All modes of fretting damage were observed: Fretting wear was found for high micromotions in combination with low contact pressures. Fretting fatigue occurred with reduced movement or increased contact pressures. With small micromotions or high normal pressures, low fretting damage was observed. The developed device can be used to evaluate taper design (and especially contact geometry) as well as different materials prior to clinical use.

1. Introduction

Modular total hip arthroplasty (THA) prostheses facilitate optimized implant fixation and adjust hip biomechanics [1]. Since the beginning of the 1970s modular head neck components have been used to vary head length and diameter independent of the stem. In the 1990s first modular double taper necks were introduced to adjust length, anteversion and femur offset intraoperatively [2–4]. The downside of this implant design is an additional modular interface with a potential susceptibility to fretting and crevice corrosion [5]. Several fractures of modular neck adapters have been documented recently [2,6–8], due to a combination of different factors. Apart from the high and unfavorable mechanical loading in the modular coupling, contamination at the interface plays an important role [9].

The critical surface damage in the interface between stem and neck adapter of bi-modular titanium alloy hip prostheses failures was associated in the majority of cases with fretting [2,6,10], defined as the relative oscillatory tangential movement of small amplitude which may occur between contacting surfaces subjected to vibration or cyclic stressing [11]. The fretting map approach introduced by Vingsbo and Soederberg [12] characterizes the fretting contact according to applied load and amplitude of micromotions into stick-, stick-slip and gross slip conditions. Subsequently, based on material response, Zhou et al. [13] identified different modes of surface degradation: low damage wear, cracking and particle detachment with increasing fretting fatigue. In the

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presence of body fluids, fretting can be accompanied by corrosive effects (fretting corrosion) [14].

Modular junctions in THA are exposed to fretting motion and also to penetration by body fluids [15]. Cobalt–chromium (Co–Cr) and titanium alloys are mainly used for this application in a mixed (Ti–6Al–4V/Co–Cr) or similar material combination (Ti–6Al–4V/Ti–6Al–4V, Co–Cr/Co–Cr). The Ti–6Al–4V alloy exhibits excellent biocompatibility and strength characteristics, but unlike the Co–Cr alloy, it is susceptible to fretting damage.

The pre-clinical testing of the stem–neck interface of a modular hip implant under physiological conditions is a prerequisite to prevent fretting-induced failures in the patient. Different tests have been developed to simulate the contact conditions at the neck–head interface [16], at the stem–cement interface [17] and at the stem–bone interface [18]. In contrary to these interfaces, the surfaces at the taper interface between stem and neck are exposed to high contact pressure and micromotions up to 50 μm under cyclic loading due to the high bending component in the load [19].

In order to allow conclusive pre-clinical testing of the micromotion magnitude at taper connections, the influence of interface micromotions and applied contact pressure on the fretting fatigue performance of Ti–6Al–4V titanium alloy couplings used in modular hip joint replacements was quantified with a newly developed fretting test setup.

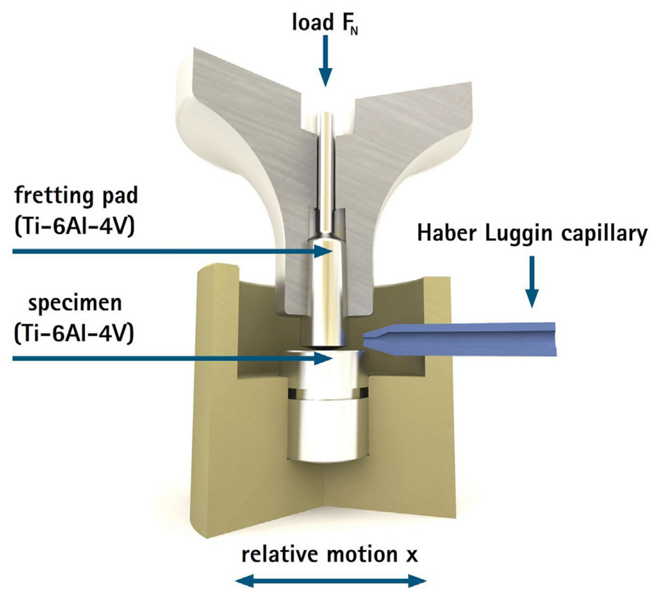

Fig. 2. Schematic view of the measuring cell showing the sphere-on plane contact between fretting pad and specimen.

2. Materials and methods

2.1. Experimental device

The fretting tests were performed on a newly developed experimental testing system for in vitro examination of fretting damage (Fig. 1). In order to simulate the oscillatory tangential movement, a sinusoidal displacement is generated by a linear preloaded piezo-actuator P-845.60 and a piezo-servo controller E-625 (Physik Instrumente GmbH & Co. KG, Karlsruhe, Germany). The maximum range of the piezo-actuator is 90 μm with a maximum push/pull force of −3000 N and +700 N. The piezo-translator is equipped with an integrated strain gauge sensor (SGS) with a high measurement resolution of 1.8 nm in closed-loop operation. The displacements of the specimen are recorded by a laser nano sensor optoNCDT 1401-5 with a measurement resolution of 0.6 μm and range of 5 mm (Micro-Epsilon Messtechnik GmbH & Co. KG, Ortenburg, Germany).

The measuring cell (Fig. 2) is mounted on a precision linear slide unit in a high rigid die set (Fibro GmbH, Weinsberg, Germany). As the piezo-actuator can only exert compressive force on the carriage, the system is pre-strained with a compressive spring to 500 N. The tangential force is measured by a piezoelectric force sensor (9011A, Kistler Holding AG, Winterthur, Switzerland). The normal load is applied up to a maximum force of 500 N by a precompressed spring on the fretting pad and monitored by a 500 N load cell (C9B, Hottinger Baldwin Messtechnik GmbH, Darmstadt, Germany). The contact stamp is pressed on the fretting sample which is fixed in the measuring cell.

Potential measurements are carried out with a three-electrode arrangement with an electrolyte bridge to analyze the corrosion behavior. The potential of the working electrode (specimen) is measured against a reference electrode (Ag/AgCl electrode) using a Haber-Luggin capillary. Ringer's solution is used at ambient conditions to simulate physiological fluids (B. Braun AG, Melsungen, Germany).

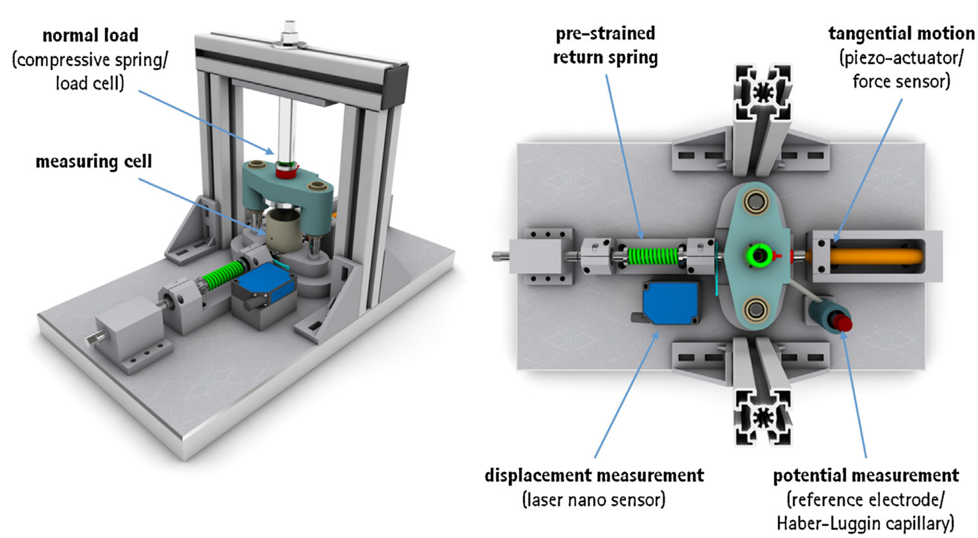

Fig. 1. Experimental fretting test setup.