



Experimental and numerical study of cemented bone-implant interface behaviour

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ABSTRACT. The quality of bonding between the acetabular cup and pelvis bone plays a key role in total hip replacement stability. One of the source of potential loss of the primary stability is the cement layer degradation. The aim of the research was to investigate the cemented bone-implant interface behavior. The main problems (cement layer degradation and bone-cement interface debonding) during physiological loading conditions [2] have been investigated using a custom hip simulator. The experimental setup was designed to allow cyclic loading of the sample of pelvic bone with implanted cemented acetabular component. The hip contact force of required direction and magnitude was applied to the implant using a spherical femoral component head. The most unfavorable activity (downstairs walking) was simulated in two million cycles with 4 Hz frequency [1]. The pelvic bone was supported by an epoxy mould. The bone was moistened by saline solution. The process of damage accumulation in cement fixation was monitored by repeated scanning using high resolution micro Computed Tomography (μ CT). Use of microfocus source and large high resolution flat panel detector allows investigation of structural changes as well as development of full-scale micro-structural models.

KEYWORDS. Bone-cement interface; Hip simulator, μ CT

INTRODUCTION

A septic loosening is one of the most frequent reasons of failure of total hip joint replacement. The aim of the research was to investigate the processes playing role during cement degradation. To determine the degradation caused by cyclic mechanical loading radiological investigation have been used. The main problem of loosening – cement layer degradation and bone-cement interface debonding – have been investigated using a custom hip simulator. Image data from μ CT were used to reconstruct the complex geometry of the inner structure of the trabecular bone and the

interface between the pelvic bone and the implant. Visualisation of trabecular bone structure and cement layer changes provided information about implant instability progress.

BONE SPECIMEN

The experiments and measurements were carried out using wet formalin-stored anatomical specimen of human hemipelvic bone. With regards to microtomography device detector size it was necessary to cut down the specimen to fit the detector. The bone was resected in ischial, pubic and iliac part; the acetabular area remained intact. The pelvis was scanned using a custom microtomography device. After the scanning of the intact acetabular region, cemented acetabular cup with made from ultra-high molecular weight polyethylene (UHMWPE) was implanted and rescanned. In the next step, a cyclic loading test was performed and the bone was scanned again.

LOADING TEST

New hip joint simulator was developed for acetabular implant testing. The experimental setup was designed to allow cyclic loading of the sample of pelvic bone with implanted cemented acetabular component. The simulator was designed as an accessory for Instron 1343 and Instron 1603 loading machines. Model 1603 is electro magnetic resonance fatigue tester suited for high frequency dynamic loading. Fatigue tests were carried out mainly using servo-hydraulic Instron 1603 suitable for both static and dynamic testing. The crosshead was operated hydraulically. The outputs of the force and displacement transducers were captured with sampling frequency up to 10 Hz. The force driven loading had a sinusoidal run. The hip contact force of required direction and magnitude was applied to the implant using spherical femoral component head. According to hip contact forces measurement [2] mean value 1500 N and amplitude 1000 N was chosen to simulate the most unfavorable activity (downstairs walking) with 4 Hz frequency. This frequency is higher than normal walking but without any effect to implant durability [1]. The pelvic bone was supported by an epoxy mould. The bone was moistened by saline solution.

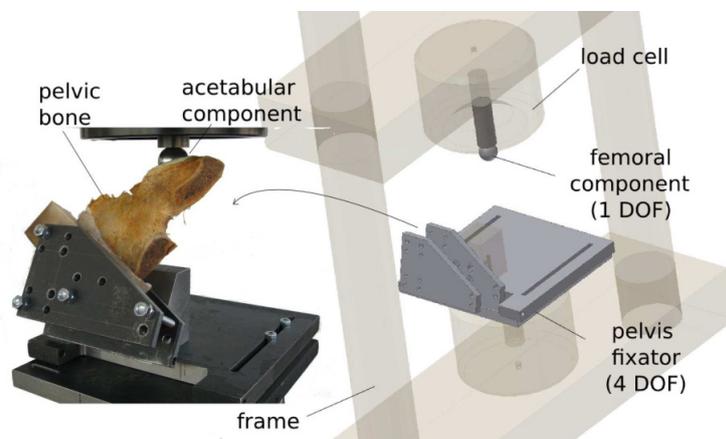


Figure 1: Hip joint simulator.

MICROTOMOGRAPHY MEASUREMENT

A custom microtomography device was used to obtain the X-ray images of the acetabular region. Manipulation with the X-ray source, the table with the specimen and the detector were provided by stepper motors using a USB interface, controlled by Pixelman [3] software plug-in. Microfocus X-ray source Hamamatsu L8601-01 with wolfram anode was used. For this purpose flat panel detector (FPD) with thin-film transistor (TFT) construction was used. Signal detected at each pixel of the detector was integrated to the memory. Physical dimensions of the detector are 120×120 mm with maximal resolution of 4 Mpx. The pelvic bone was fixed in the iliac area onto a rotating table to leave the acetabular region exposed for scanning. Scanning sequence consisted of 360 scans with 1° step increment.



MODEL DEVELOPMENT

The three-dimensional geometry of the acetabulum was reconstructed from sequence of two-dimensional matrices. Every single element of the matrix represents output emission intensity I on detector. Relationship between input and output intensity is given by:

$$\frac{I_0}{I} = e^{\mu_T d} \quad (1)$$

where I_0 is the value of input emission emitted by X-ray source, d is the thickness of the specimen and μ_T is linear coefficient of absorption [4]. To make a correct reconstruction it was necessary to accomplish several corrective procedures.

The result of the reconstruction was a sequence of slices or 3D matrix containing the object with visible inner microstructure [6]. Reconstructed data were visualized by μ CTvis [7]. This software enables to display the slices in YX, YZ, XZ planes, to segment and smooth the data. μ CT modeller [8] was used to development of model. Both surface and voxel FE models of the whole object or its part could be created. This software tools are based on open source Visualization Toolkit (VTK) libraries.

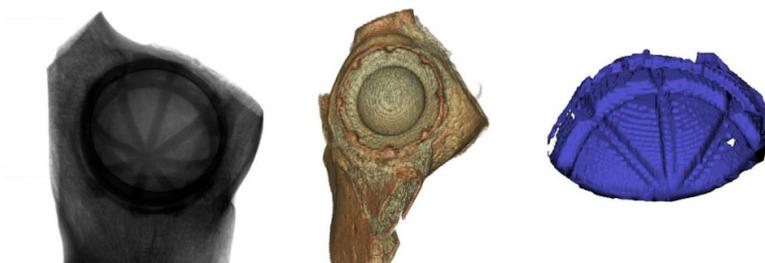


Figure 2: Cement layer FE model development (radiogram, pelvis visualisation and damaged cement layer FE model)

CONCLUSIONS

A failure in cemented acetabular implant – debonding, crumbling and smeared cracks – has been found to be at the bone-cement interface, based on a new hip simulator study. Use of micro-focus source and high resolution flat panel detector of large physical dimensions allows for reconstruction of full-scale micro-structural models. These models are suitable for investigation of structural changes in case of osteoporosis as well as for research of trabeculae micro-damage and total hip joint replacement behaviour. Migration, micro-motions and consecutive loosening of the implant could be observed by this method. The failure mechanism is consistent with clinically observed degradation process. Presented study utilizing a new hip simulator reduces the required time significantly than under physiological loading conditions in human body.

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REFERENCES

- [1] J. Tong, N. P. Zant, J.-Y. Wang, P. Heaton-Adegbile, J.G. Hussell, International Journal of Fatigue 30(8) (2008) 1366.
- [2] G. Bergmann, G. Deuretzbacher, M. Heller, F. Graichen, A. Rohlmann, J. Strauss, G. Duda, Journal of



- Biomechanics (2001).
- [3] T. Holý, J. Jakůbek: Pixelman software package - data acquisition and control of semiconductor pixel device Medipix, (2007).
- [4] J. Jakůbek, A. Cejnarová, T. Holý, S. Pospíšil, J. Uher, Z. Vykydal, Nuclear Instruments and Methods in Physics Research (2007).
- [5] D. Vavřík, T. Holý, J. Jakůbek, M. Jakůbek, J. Valach, Czechoslovak Journal of Physics (2008)
- [6] D. Kytýř, O. Jiroušek, D. Vavřík, Engineering Mechanics (2009).
- [7] P. Zlámal, O. Jiroušek, μ CTmodeller - creating solid and Finite Element models from microCT (2009).
- [8] P. Zlámal, O. Jiroušek, μ CTvis - visualization of microfocus Computed Tomography data, (2009).