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Time-lapse micro-CT Analysis of Fatigue Microcrack Propagation in Cortical Bone

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A bone microcrack under physiological condition can be defined as a fissure in the hydroxyapatite matrix caused by damage accumulation over the limit of remodeling process [1]. Microdamage accumulation accelerated by process of aging and metabolic diseases decreases bone strength and finally leads to loose of primal stability and bearing capacity of the bone. Understanding the fatigue cracking mechanism of the bone and identification of the relevant mechanical properties is a key element for the further improvements in design of bone scaffolds and replacements. In this paper, time-lapse micro-tomography (micro-CT) analysis is used as a method for the identification of the fatigue microcracks in human cortical bone. Custom design table-top loading device with a bioreactor chamber [2] was employed for in-situ fatigue loading directly in the X-ray scanner. The specimen of the human cortical bone was submerged in the circulating simulated body fluid with controlled temperature approx. 37℃ to represent real conditions of the human body. Initial defects in the bone were induced by the first loading step with peak force sufficient for the crack initiation. After the first loading step, thin (approx. 5-10 micrometers) longitudinal microcracks formed in the bone microstructure. Then, in-situ fatigue loading was performed to induce propagation of the microcracks. Loading increments of several thousand load cycles with period of approx. 2 seconds were used to investigate crack propagation phenomena. The fatigue testing was ended after approx. 20 thousand cycles. During the overall experimental process, the in-situ loading device was mounted on the rotary stage of the X-ray scanner and the tested specimen was scanned using high-resolution micro-CT in the representative loading steps (before initiation of the microcracks, directly after the initiation and each time after a defined increment of fatigue cycles was reached). The micro-CT scans were performed using the modular X-ray imaging device TORATOM. In this study, a XWT-160-THCR transmission type X-ray tube with maximum tube voltage 160 kV, target power 25 W and minimum focal spot size 1 micrometer was used together with a flat panel X-ray detector Dexela 1512NDT for the acquisition of the X-ray images. The detector is based on CMOS (Complementary Metal–Oxide–Semiconductor) semiconductor technology and is equipped with an oriented CsI scintillator. The active area of the detector is 145.4 mm x 114.9 mm with pixel matrix of 1944 x 1536 pixels with pixel pitch of 74.8 micrometers and maximum frame-rate of 26 fps. The X-ray energy range of the detector is 12 - 160 keV making it suitable for imaging of bone samples. The individual micro-CT reconstructions of the specimen were processed using a differential tomography algorithm for identification of the individual microcracks in the microstructure and for investigation of the crack propagation phenomena. The micro-tomography results were compared with the results from the in-situ loading device recorded during the fatigue testing and the overview of the fatigue damage mechanism was introduced.

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