2024 年 11 月 25～29 日に松江で開催された「破壊と強度に関するアジア-太平洋会議」（the 14th Asia-Pacific Conference on Fracture and Strength (APCFS 2024)）において、以下の研究発表を行いました。本研究は、公益財団法人ＪＫＡによる競輪の補助を受けて実施しました。

Enhancement of Fatigue Strength and Biocompatibility of Ti-6Al-4V by Low-energy Laser Peening

Kyosuke Sugiyama*, Yuji Sano**,***, Yoshio Mizuta**, Satoshi Tamaki**, Takahisa Shobu****, Ai Momozawa*****, and Koichi Akita******

*Graduate school, Tokyo City University, 1-28-1 Tamazutsumi, Setagaya-ku, Tokyo 158-8557, Japan

**Department of Quantum Beam Physics, SANKEN, Osaka University, 8-1 Mihogaoka, Ibaraki 567-0047, Japan

*** Institute for Molecular Science, National Institutes of Natural Sciences, 38 Nishigo-Naka, Myodaiji, Okazaki 444-8585, Japan

**** Materials Sciences Research Center, Japan Atomic Energy Agency, Tokai, Ibaraki 319-1195, Japan

*****Department of Medical Engineering, Tokyo City University, 1-28-1 Tamazutsumi, Setagaya-ku, Tokyo 158-8557, Japan

******Dept. of Mechanical Systems Engineering, Tokyo City University, 1-28-1 Tamazutsumi, Setagaya-ku, Tokyo 158-8557, Japan

E-mail: akitak@tcu.ac.jp

Abstract

In recent years, the world's population has been ageing and attention has been focused on extending healthy life expectancy. As people age, tooth loss and periodontal disease drive demand for dental implants, which restore chewing, speech, and overall well-being, promoting healthy aging. However, in dentistry and oral surgery, increased use of dental implants has led to reports of fatigue-related fractures and slippage due to poor cell anchorage. To prevent these accidents, both fatigue strength and biocompatibility of implants are required, but there have been reports of reduced fatigue strength due to the influence of surface roughness introduced in the process of improving biocompatibility.

In this study, we successfully enhanced both the fatigue strength and biocompatibility of a medical-grade titanium alloy, Ti-6Al-4V ELI, which is used as a fixture in dental implants, embedded in bone tissue and subjected to significant loads. This was achieved by applying Low-energy Laser Peening (LELP), a technique recently developed by Sano et al., one of the co-authors of this paper, using a laser pulse energy of less than 10 mJ.

First, the LELP was applied to the surface of a 3mm diameter round bar made of Ti-6Al-4V ELI, and the surface residual stress was measured using X-ray diffraction. As a result, it was confirmed that LELP introduced high compressive residual stresses at the surface, reaching the material's yield point. Additionally, the depth of the introduced compressive residual stress was very shallow, approximately 100 micrometers, compared to conventional laser peening (CLP) using a 200 mJ laser pulse energy. This shallow depth of residual stress contributed to significantly lower balancing tensile residual stress within the material compared to CLP. Fatigue testing of the specimens demonstrated a substantial improvement in fatigue strength. It is considered that the high compressive residual stress at the surface extended the crack initiation life, and due to the low internal tensile residual stress, internal cracking that could induce premature failure did not occur.

Next, to evaluate the biocompatibility of the LELP-treated surface, cell culture tests were conducted using the mouse osteoblast cell line MC3T3-E1 and cell culture medium α-MEM+FBS (10%). The results confirmed that, compared to untreated material, the initial cell adhesion was more favorable on the LELP treated surface, which can be attributed to the fact that the LELP-treated surface possesses an optimal level of roughness, enhancing its biocompatibility.

This study demonstrates that LELP holds significant promise not only for dental implants but potentially for other biomedical applications where both high fatigue strength and excellent biocompatibility are crucial. The ability to achieve these improvements in a single processing step could lead to more durable and reliable medical devices, improving patient outcomes in an aging population.

Keywords: Low-energy laser peening (LELP), Ti-6Al-4V, Fatigue, Biocompatibility, Implant

●問い合わせ先：本研究の詳細は、当研究室の秋田（akitak[at]tcu.ac.jp　[at]→@）にお問い合わせください。