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Dimensional consistency of SLM printed orthopaedic implants designed using lightweight structures

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Abstract: To solve the stress shielding problem in the orthopaedic implants applications, lightweight lattice structures were designed to optimize the internal of implants. The variation of truss size of lattices can affect the mechanical performances of implants. Also the printed dimension of the shell is closely related to the fitting of implants, and its thickness will again affect the mechanical property of the printed implants. In this study, high resolution X-ray computed tomography was used to quantitatively investigate the consistency of the dimensions in the designed and printed orthopaedic implants.

I. Introduction

Due to the availability and relatively low cost, Stainless Steel (SS) 316L is widely used for Orthopaedic trauma implants such as fracture fixation plates [1]. However, the young's modulus of SS316L is at around 200 GPa, which is significantly higher than that of the cortical bone, which is 18 - 20 GPa [2]. High mismatching in the young's modulus of SS316L and cortical bone can cause stress shielding in implant applications. This can affect the local biomechanical environment around a fractured bone and may lead to delayed union or non-union [3].

Additive manufacturing (AM) technology coupled with lightweight and low modulus designs support a rapid transition from innovative designs to final products. Several studies have reported different design concepts of low modulus, lightweight Orthopaedic implants fabricated using AM technology. They have suggested that the bone in-growth characteristics of such implants can be optimized for specific locations within the body [4, 5]. However, few studies have addressed the issue of printing accuracy when the internal structure was optimized using lattices. The potential variance between planned and actual strut diameter raises concerns about the mechanical properties as well as the external dimensions of implants.

In this study several different lattice designs were applied as the internal structure of a simplified model based on classic Orthopaedic implants (the dynamic compression plate, DCP). The consistency of truss diameter of the internal lattices and thickness of the external structural shell were examined using high resolution X-ray Computed Tomography (XCT).

II. Material and methods

In our study, several bone plates were designed, printed and tested under ASTM F382 (testing method for metallic bone plates). Three optimized lattice designs with a low young's modulus but comparably good bending stiffness were selected as the internal structure of the new DCP (Fig. 1). These newly designed plates with internal lattice structures were then manufactured via SLM (Fig. 2).

All the SS316L plates were manufactured by 3D Metal Forge Singapore, using a Renishaw AM 400 (Renishaw, United Kingdom). The key printing parameters are shown in table 1. The printing accuracy of the newly designed implants were subsequently evaluated using high resolution XCT from GE Nanotom M (General Electric Company, United States). After reconstruction of the 3D volume model, VG studio Max3.0 (Volume Graphics GmbH, Germany) was used to analysis the geometrical features, both internally and externally.

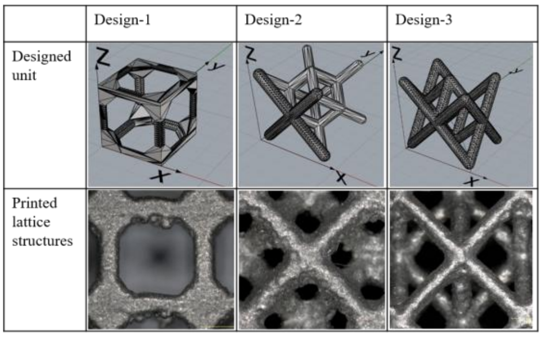

Figure 1: Three selected lattice designs with good bending stiffness but low young's modulus.

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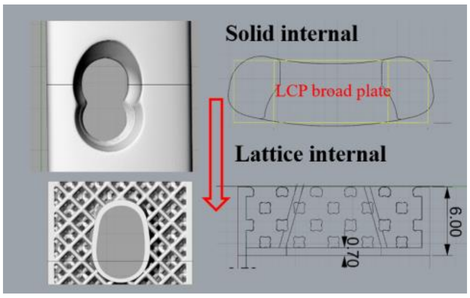

Figure 2: The redesigned orthopaedic implant with the cross-section demonstrated.

Table 1: The optimized printing parameters used in SLM.

1) Laser Power	200 W
2) Scan Speed	600 mm/second
3) Hatch Distance	0.06 mm
4) Layer Thickness	0.05 mm

III. Results and discussion

The radius of the trusses and the thickness of the external shell were quantitatively examined using high resolution XCT. Fig. 3 demonstrates the cross-sectional view of a plate and its lattice. Five measurements were conducted at different locations of the lattice. This was repeated multiple times on each of three lattice designs (Fig.1). For trusses with a radius designed at 0.3 mm, the actual radius varied from 0.31 mm to 0.43 mm. The variation appeared random, there was no relationship between lattice design, printing batches or measurement location. We believe the larger truss size observed and the random variation was caused by over printing followed by uncontrolled material removal during the post processing stages of manufacturing. The variations from 1% to 43% of the truss radius suggest the mechanical properties of the printed lattice could vary significantly from those designed or the simulated value.

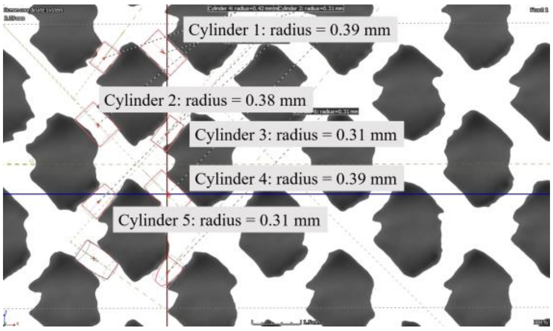

Figure 3: Illustration of the sliced cross-section of the redesigned Orthopaedic plates using lattice design-3, the radius of cylinders was measured using the fitting algorithm.

The external shells with a designed thickness of 0.7 mm, the measured thickness was varied from 0.88 mm to 0.89 mm (Fig. 4). This value was consistent across all samples. An over printing ratio of approximately 26% in the thickness of the solid shell could further modify the mechanical properties of the bone plate. Due to the consistent nature of this overprinting, it could be compensated by reducing the planned thickness or applying additional precision subtractive machining.

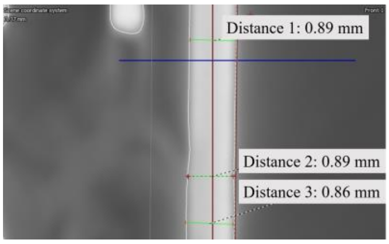

Figure 4: Illustration of the measurements of the thickness of shell on the redesigned Orthopaedic plates.

So far, no standard has been established to define the dimensional tolerances of lattice-based implants fabricated via AM. The tolerances of machined DCP plates are extremely tight in comparison to the SLM manufactured parts, additional post processing may be required for the solid external shell of implants processed via SLM.

IV. Conclusions

We have redesigned classic Orthopaedic bone plates using optimized internal lattices, with a view to reduce the implants young's modulus. In theory this may improve the biomechanical environment for fracture healing. This study aimed to define the accuracy of printing of these complex lattice designs. Using high resolution XCT we have found significant overprinting in the radius of truss and thickness of shell. The truss overprinting was random whereas the external shell overprinting was consistent and predictable. This information could be used as correction factors to evaluate the mechanical performances of the printed implants.

This study has updated the capability and realization of precision implants in the medical field. To facilitate product evolution and evaluation, we need to establish a standard for precision printing. This needs to address design, manufacturing, post processing and the effects of each on final implant performance.

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AUTHOR'S STATEMENT

Conflict of interest: Authors state no conflict of interest. Informed consent: Informed consent has been obtained from all individuals included in this study. Ethical approval: Not required

REFERENCES

[1] M. Navarro, A. Michiardi, O. Castaño, J. Planell, Biomaterials in orthopaedics, Journal of the Royal Society Interface, vol. 5(27), pp. 1137-1158, 2008.
[2] J. Y. Rho, R. B. Ashman, C. H. Turner, Young's modulus of trabecular and cortical bone material: ultrasonic and microtensile measurements, Journal of Biomechanics, vol. 26(2), pp. 111-119, 1993.
[3] R. Huiskes, H. Weinans, B. Van Rietbergen, The relationship between stress shielding and bone resorption around total hip stems and the effects of flexible materials, Clinical Orthopaedics and Related Research, vol. 274, pp. 124-134, 1992.
[4] L. Mullen, R. C. Stamp, W. K. Brooks, E. Jones, C. J. Sutcliffe, Selective laser melting: a regular unit cell approach for the manufacture of porous, titanium, bone in-growth constructs, suitable for orthopaedic applications, Applied Biomaterials, vol. 89(2), pp. 325-334, 2009.
[5] P. Heinl, L. Müller, C. Körner, R. F. Singer, F. A. Müller, Cellular Ti–6Al–4V structures with interconnected macro porosity for bone implants fabricated by selective electron beam melting, Acta Biomaterialia, vol. 4(5), pp. 1536-1544, 2008.