Evaluation on Bending Properties of Biomaterial GUM Metal Meshed Plates for Bone Graft Applications

To cite this article: Hiromichi Suzuki and Jianmei He 2017 IOP Conf. Ser.: Mater. Sci. Eng. 269 012078

View the article online for updates and enhancements.
Evaluation on Bending Properties of Biomaterial GUM Metal Meshed Plates for Bone Graft Applications

Hiromichi Suzuki\textsuperscript{1*}, Jianmei He\textsuperscript{1}

\textsuperscript{1}Dept. of Mechanical Engineering, Kogakuin Univ. 1-24-2, Nishi-shinjuku, Shinjuku-ku, Tokyo, 163-8677 Japan

Abstract. There are three bone graft methods for bone defects caused by diseases such as cancer and accident injuries: Autogenous bone grafts, Allografts and Artificial bone grafts. In this study, meshed GUM Metal plates with lower elasticity, high strength and high biocompatibility are introduced to solve the over stiffness & weight problems of ready-used metal implants. Basic mesh shapes are designed and applied to GUM Metal plates using 3D CAD modeling tools. Bending properties of prototype meshed GUM Metal plates are evaluated experimentally and analytically. Meshed plate specimens with 180°, 120° and 60° axis-symmetrical types were fabricated for 3-point bending tests. The pseudo bending elastic moduli of meshed plate specimens obtained from 3-point bending test are ranged from 4.22 GPa to 16.07 GPa, within the elasticity range of natural cortical bones from 2.0 GPa to 30.0 GPa. Analytical approach method is validated by comparison with experimental and analytical results for evaluation on bending property of meshed plates.

1. Introduction

People who have lost a part of their bones due to accidents, injuries or illnesses are subjected to bone graft surgery. This study focuses on metallic implants used for artificial bone grafts. Figure 1 shows an X-ray photograph of fixation by a metal plate in actual bone graft implantation. Conventionally used implants of titanium alloys have the problems that the burdens on the patient are increased due to their excessive rigidity and overweight than human bones. Therefore, in this study, GUM Metal plates with low elastic modulus, high strength and high biocompatibility was interested to improve these problems. The purpose of this research is to evaluate the out-of-plane bending characteristic of meshed GUM Metal plates with higher bending flexibility near to the natural bones.

\begin{figure}[h]
\centering
\includegraphics[width=0.5\textwidth]{fig1.png}
\caption{X-ray photograph of artificial bone graft.}
\end{figure}

\begin{figure}[h]
\centering
\includegraphics[width=0.5\textwidth]{fig2.png}
\caption{Cortical bone in the femur.}
\end{figure}
Basic mesh shapes are designed using 3D CAD software Solidworks. And meshed GUM Metal plate specimens are fabricated by laser-cutting processing for experimental evaluations. The mechanical properties of meshed plate implants should be close to the mechanical properties of human’s cortical bones to minimize damages on patients. Natural cortical bones as shown in figure 2 have volume density range from 0.5 to 1.1 g/cm³ and elastic modulus range from 2.0 to 30.0 GPa. On the other hand, analytical approaches on bending stiffness of meshed GUM Metal plate specimen are also carried out through finite element method and comparison with experimental results are used to validate analytical method proposed in this study.

2. Design of basic mesh shape and preparing of meshed plate specimens

2.1. Characteristics of GUM Metal plate used for meshed plate specimens

It is necessary to use materials with high biocompatibility for medical implants. Human bodies do not recognize pure titanium and titanium alloy as foreign matter, and new generated bones will catch around the titanium implants. GUM Metal is one kind of titanium alloy made by melting and recrystallizing powders of pure titanium, niobium, tantalum and zirconium. GUM Metal has mechanical performances like low elastic modulus, high strength and high biocompatibility/bioaffinity. Tensile test based on JIS Z 2241 standard was performed on GUM Metal plate used for prototype meshed plates. From experimental results, tensile elastic modulus and Poisson’s ratio of GUM Metal were calculated and shown in table 1. These mechanical properties can be used for analytical approach on prototype meshed GUM Metal plates.

Table 1. Material properties of GUM Metal plate obtained by tensile test.

| Young’s modulus [GPa] | 91.2 |
|-----------------------|------|
| Poisson’s ratio       | 0.33 |

2.2. Design of basic mesh shapes for prototype meshed plates

Basic mesh shapes are designed following design concepts shown below using 3D cad modeling tools.

1. One unified basic mesh shape to reduce designing and manufacturing costs.
2. Reduce stress concentrations to reach high strength and long operating life, by eliminating corners in the basic mesh shape and approximating the mesh line width uniformly.
3. Easy control of in-plane stretchability and out-of-plane bending characteristics by providing S-shaped curves with changed curvatures in the basic mesh shape.

Figure 3 shows the basic mesh shapes designed for prototype meshed plate applications. From left to right, 180° axisymmetric shape, 120° axisymmetric shape and 60° axisymmetric shape are obtained for experimental and analytical evaluations.

Figure 3. Basic mesh shapes designed for experimental and analytical evaluations.

2.3. Design of prototype meshed plate specimens

Four types of prototype meshed plate specimens were designed using the basic mesh shapes shown in the previous section. Figure 4 shows the respective sizes and shapes of prototype meshed plate models. All of them have same mesh line width of 0.8 mm. 180° prototype model is obtained by rotating 60° of 180° axisymmetric basic mesh shape and having most in-plane isotropy performance. Difference
between 120° and 120° (revers) prototype models is reversed of the central array of 120° axisymmetric basic mesh shape.

![Prototype meshed plate models for experimental and analytical evaluations.](image)

**Figure 4.** Prototype meshed plate models for experimental and analytical evaluations.

### 2.4. Evaluation on volume density of prototype meshed plates

Prototype meshed plate models become light-weight structures because of the applied basic mesh shapes. Then the volume densities of meshed GUM Metal plate models can be calculated from equation (1) and the results are shown in figure 5 comparing with no-meshed GUM Metal plate.

\[
\text{Volume density} = \frac{\text{Mass after mesh processing}}{\text{Volume before mesh processing}}
\]

\[\text{(1)}\]

![Meshed plate shape models for sample specimen evaluations.](image)

**Figure 5.** Meshed plate shape models for sample specimen evaluations.

From figure 5, one can see that prototype GUM Metal Plate models are significantly reduced in weight by mesh processing. It is confirmed that the weight characteristics of meshed GUM Metal plate models are approached close to the volume density of human cortical bones range from 0.5 to 1.1 g/cm³ through applying the basic mesh shapes.

![Three-point bending test.](image)

**Figure 6.** Three-point bending test.

![Meshed plate specimens for 3-point bending test.](image)

**Figure 7.** Meshed plate specimens for 3-point bending test.

### 3. Bending property evaluation of prototype meshed GUM Metal plates

Three-point bending tests for three kinds of prototype meshed GUM Metal plates were carried out based on JIS Z 2248 (Metal material bending test method) standard. Figure 6 shows the photo image of three-point bending test and figure 7 shows the prototype meshed plate specimens.
Based on the loading-deflection result of three-point bending test, bending pseudoelastic modulus $E$ of sample meshed plate specimens can be calculated from equation (2).

$$E = \frac{P l^3}{48 l \delta}$$

(2)

where $P$ represents bending load, $\delta$ represents bending deflection, $l$ represents the distance between supporting points of three-point bending test and $P / \delta = \tan \theta$ can be obtained from loading-deflection diagram. The angle $\theta$ shows the inclination of the load-deflection diagram in the linear elastic range of the three-point bending test result.

4. Analytical evaluation on bending properties of meshed plate specimens

Analytical approach on evaluation of bending characteristics for meshed plate specimens were executed through finite element method. Figure 8 shows analytical model of three point bending test on meshed plate specimen with support fixture and loading jig. Bending load is set at 1.0 N perpendicular to the meshed plate. Further, the contact conditions between support fixture and meshed plate specimen were defined as "having friction". The values of friction coefficient and vertical stiffness were taken into account. On the other hand, contact condition between loading jig and meshed plate specimen was set as "solid bond". Table 2 shows detailed friction coefficients and vertical stiffness coefficient for different prototype meshed GUM Metal plates. Material model of GUM Metal plates are based on the tensile test results as shown in table 1.

Figure 9 and table 3 show details about finite element meshes of different prototype meshed plates. The bending pseudoelastic modulus of prototype meshed plates were calculated using the analytical results of deflection under 1.0 N bending load and equation (2) shown in previous section.

![Figure 8. Analytical model of 3-point bending test.](image1)

![Figure 9. Meshed specimen.](image2)

Table 2. Contact condition of model analysis.

| Types of analysis models | Friction coefficient | Vertical stiffness coefficient |
|-------------------------|----------------------|------------------------------|
| 180°                    | 0.08                 | 0.00015                      |
| 120°                    | 0.07                 | 0.00004                      |
| 120°(revers)            | 0.09                 | 0.00007                      |
| 60°                     | 0.009                | 0.00001                      |

Table 3. Details of mesh split.

| Types of analysis models | Node quantities | Element quantities | Sweep split quantities | Element size [mm] |
|-------------------------|-----------------|--------------------|------------------------|-------------------|
| 180°                    | 171792          | 117688             | 5                      | 0.2               |
| 120°                    | 237966          | 170987             | 5                      | 0.15              |
| 120°(revers)            | 239478          | 171597             | 5                      | 0.15              |
| 60°                     | 136824          | 92296              | 5                      | 0.2               |
Figure 10 shows the analytical bending pseudoelastic modulus calculated with experimental results for comparison. From the results shown in figure 10, one can see that the 180° axisymmetric meshed plate specimen shows the highest bending pseudoelastic modulus compared with other axisymmetric meshed plate specimens. The range of bending pseudoelastic modulus obtained from these four type meshed plate specimens are from 4.22 GPa to 16.07 GPa, which is closed to the elastic modulus of natural cortical bones range from 2.0 to 30.0 GPa. In addition, deviations between analytical and experimental results on 3-point bending test of prototype meshed GUM Metal plates are very small. That validate the proposed analytical method here and more detail parameteric examinations can be carried out on bending property evaluation through analytical approaches.

**Figure 10.** Experimental and analytical bending pseudo elastic modulus of meshed plate specimens.

5. Summary

Based on three type of axisymmetric basic mesh shape designed in this study, prototype meshed GUM Metal plates are fabricated for experimental evaluation. From the bending pseudoelastic modulus results of meshed plate specimens obtained experimentally and analytically, the following conclusions are reached.

1. It is possible to process a lightweight meshed GUM Metal plate for bone graft application. More than 50% of volume density reduction can be obtained by applying the basic mesh shapes on GUM Metal plates and close to the value of natural cortical bones.

2. The range of bending pseudoelastic modulus obtained from the four type meshed plate specimens introduced are from 4.22 GPa to 16.07 GPa with higher flexibility, which is closed to elastic modulus of natural cortical bones range from 2.0 to 30.0 GPa.

3. Deviations between analytical and experimental results on 3-point bending test of prototype meshed GUM Metal plates are very small. That validate the proposed analytical method here and more detail parameteric examinations will be carried out on bending property evaluation through analytical approaches in future study.

6. References

[1] Ohara H 2017 *Study on bending property of titanium alloy meshed plate for implant*, Graduate School of Engineering.

[2] Kokubo K, Goto Y, Mori Y and Tateno T *Mechanical Engineering Basic Course Material Mechanics* Maruzen Co., Ltd.

[3] Introduction of GUMMETAL <http://www.nissey-sabae.co.jp/wp/wp-content/uploads/gummetal.pdf>, (Reference Date July 10, 2017)

[4] Moriyama Neurosurgery

[5] <https://www.moriyama-neurosurgical-clinic.com/>, (Reference Date July 27, 2017)

[6] Astellas Pharma

[7] <https://www.astellas.com/jp/>, (Reference Date July 27, 2017)