Mechanical Strength Analysis of Extracoronal Magnetic Attachment by Three-Dimensional Finite Element Method

-Report II Introduction of elasto-plastic analysis-

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Introduction

We have developed extracoronal magnetic attachments for vital teeth, and they are widely used in clinical practice. However, the mechanical strength of such magnetic attachments is not fully confirmed. Ohno from our department reported the mechanical strength analysis of an extracoronal magnetic attachment using Au-Ag-Pd alloy by three-dimensional finite element method in the 21st Conference on Magnetic Applications in Dentistry. However, platinum gold alloy is more frequently used than Au-Ag-Pd alloy in clinical practice.

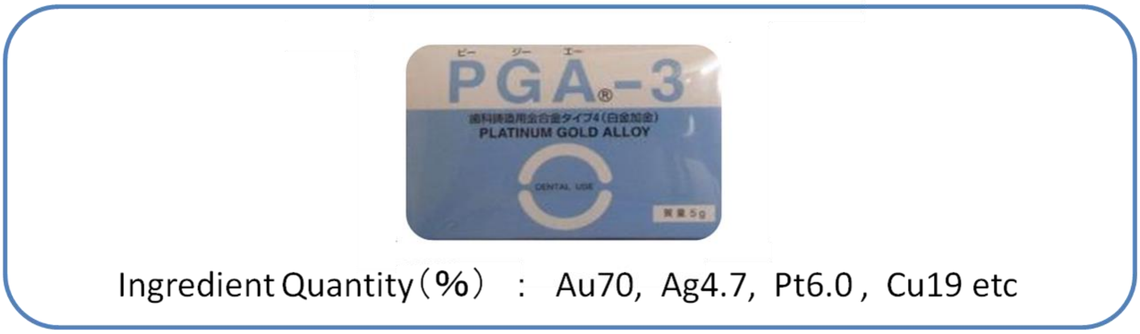
In the present study, we focused on heat treatment of platinum gold alloy, and mechanical strength analysis of an extracoronal magnetic attachment was performed.

Objective

The purpose of the present study was to investigate mechanical strength of platinum gold extracoronal magnetic attachment up to the elastic limit.

Materials and Methods

As a preliminary experiment, the stress-strain curve of dental gold casting alloy (PGA-3, ISHIFUKU Metal Industry Co., Ltd(Fig.1) after heat treatment was calculated, followed by the elasto-plastic analysis of a simple-shaped sample based on the stress-strain curve. The finite element model of an extracoronal magnetic attachment was fabricated, and elasto-plastic analysis was performed to examine mechanical strength of extracoronal magnetic attachments.



Ingredient Quantity（%） ： Au70, Ag4.7, Pt6.0 , Cu19 etc

Fig. 1 Use metal:PGA-3(ISHIFUKU)

1. Preliminary experiment

1) Stress-strain curve

The size of a sample was 2 mm in diameter (parallel area), 25 mm in the distance between marks, and 55 mm in full length. PGA-3 (ISHIFUKU Metal Industry Co., Ltd) suitable for milling and applied to abutment teeth of extracoronal magnetic attachments in our university was used for the study (Fig. 2).

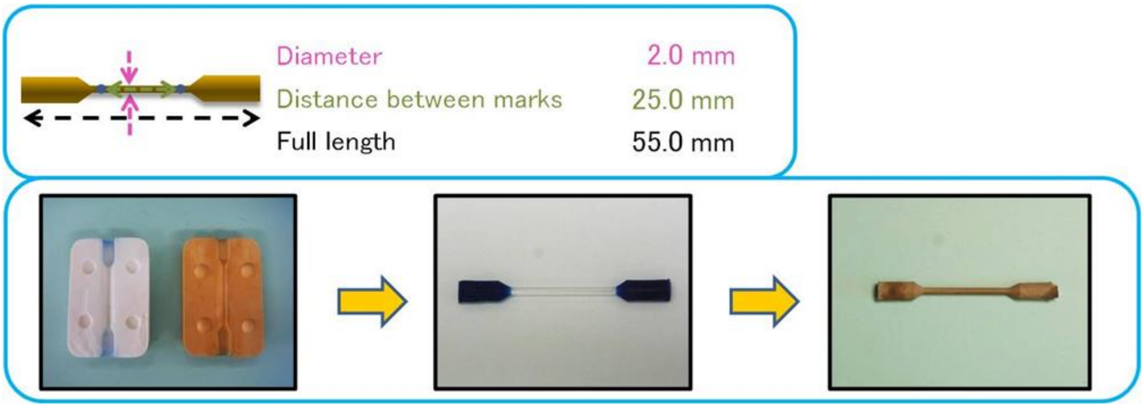


Fig. 2 Sample fabrication

Samples were invested, cast, and heat treated under the manufacturer’s instructions. Samples with hardening heat treatment, no heat treatment, and softening heat treatment were prepared (7 each). Stress-strain measurement was performed using the Instron Universal Tester (Instron Japan) with a crosshead speed of 0.5 mm / min (Fig. 3).

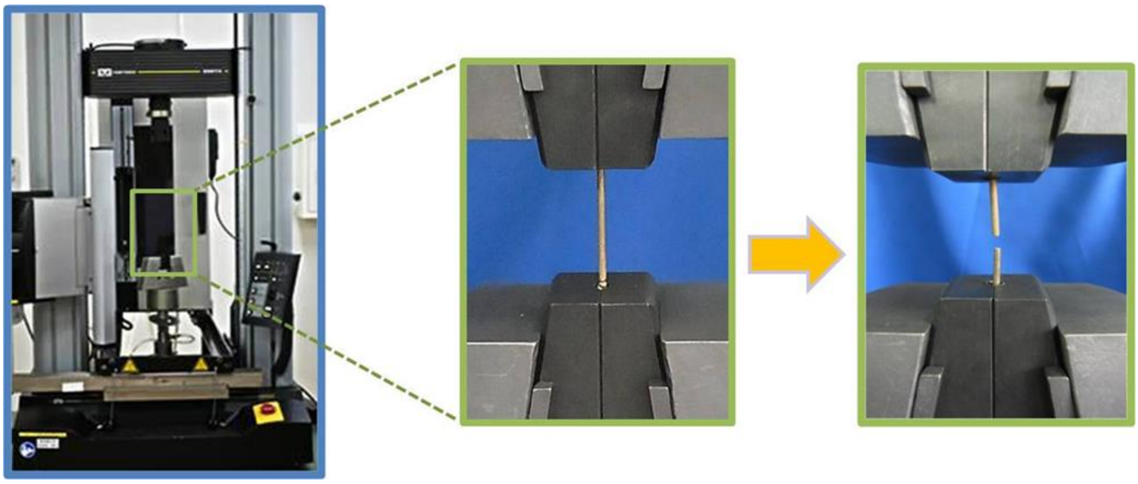


Fig. 3 Tensile test

The slopes of the strain amount in the elastic region were calculated. An inflection point and the following behavior in the plastic region were plotted to complete the stress-strain curve. The stress-strain curve was introduced to the exploratory analysis to examine the consistency of the elasto-plastic analysis.

2) Load displacement curve

The size of a sample was 7.0 mm in minor axis, 35.0 mm in diameter, and 1.6 mm in thickness (Fig. 4).

Fig. 4 Sample size and Sample

Samples were invested, cast, and heat treated under the manufacturer’s instructions. Seven samples were prepared for each treatment. Load displacement was measured using the Instron Universal Tester with a crosshead speed of 0.5 mm / min.

2. Exploratory analysis

Fig. 5 shows the size of an exploratory analysis model.

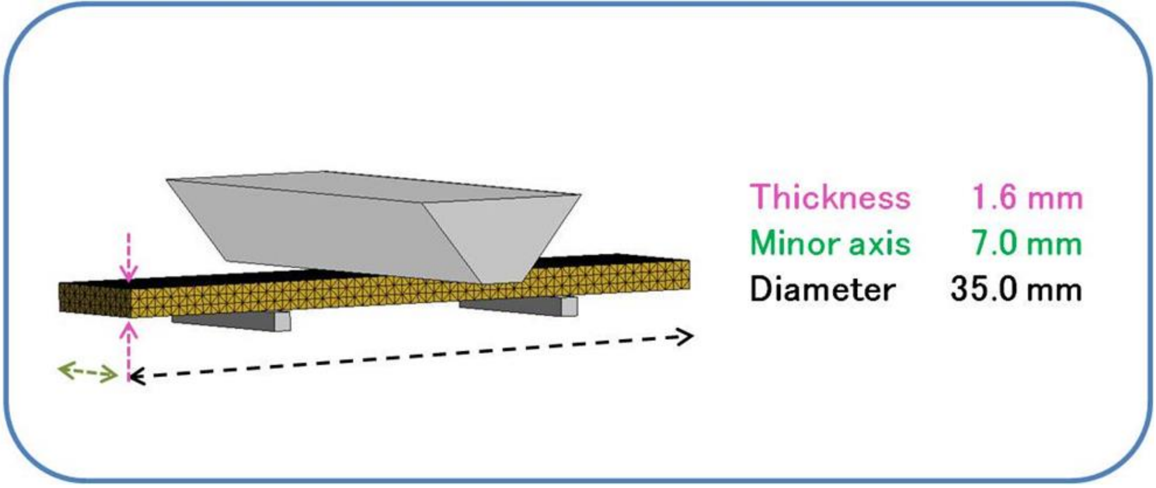


Fig. 5 Size of an exploratory analysis model

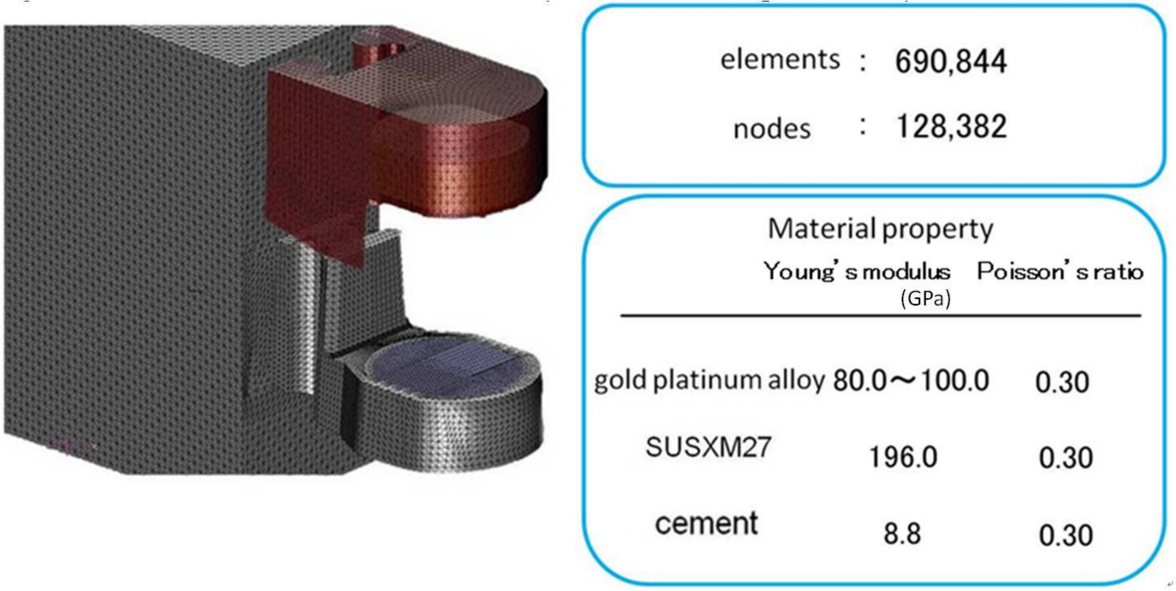
Elements and nodes were 5,164 and 23,288, respectively.

Constraint condition was applied in one direction to Z axis, and a rigid body simulating an indenter was placed at the center of a plate at 0.5 mm / min.

For material constants, the elastic coefficient of platinum gold alloy and material property in the plastic region were introduced from the stress-strain curve of the preliminary experiment for the analysis.

3. Actual analysis

Fig. 6 shows elements and nodes, and boundary condition of the present analysis.



elements : 690,844

nodes : 128,382

Material property

	Young’s modulus (GPa)	Poisson’s ratio
gold platinum alloy	80.0〜100.0	0.30
SUSXM27	196.0	0.30
cement	8.8	0.30

Fig.6 Analysis model and boundary condition

The base and extracoronal model were fabricated together. A model was fabricated by cementing a keeper and attaching a housing on top of it.

A complete constraint was applied to the top, bottom, and back surfaces in the X, Y, and Z directions.

A load was applied at the center of the extracoronal attachment in the Z axis direction for 5 minutes at a rate of 0.5 mm / min (Fig. 7).

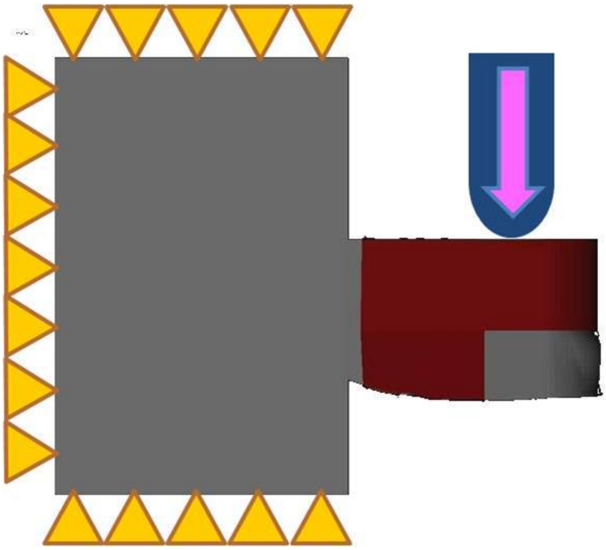


Fig. 7 Constraint condition of the present analysis model

The same method was employed for material constants, and the elastic coefficient of platinum gold alloy and material property in the plastic region were introduced from the stress-strain curve of the preliminary experiment for the analysis.

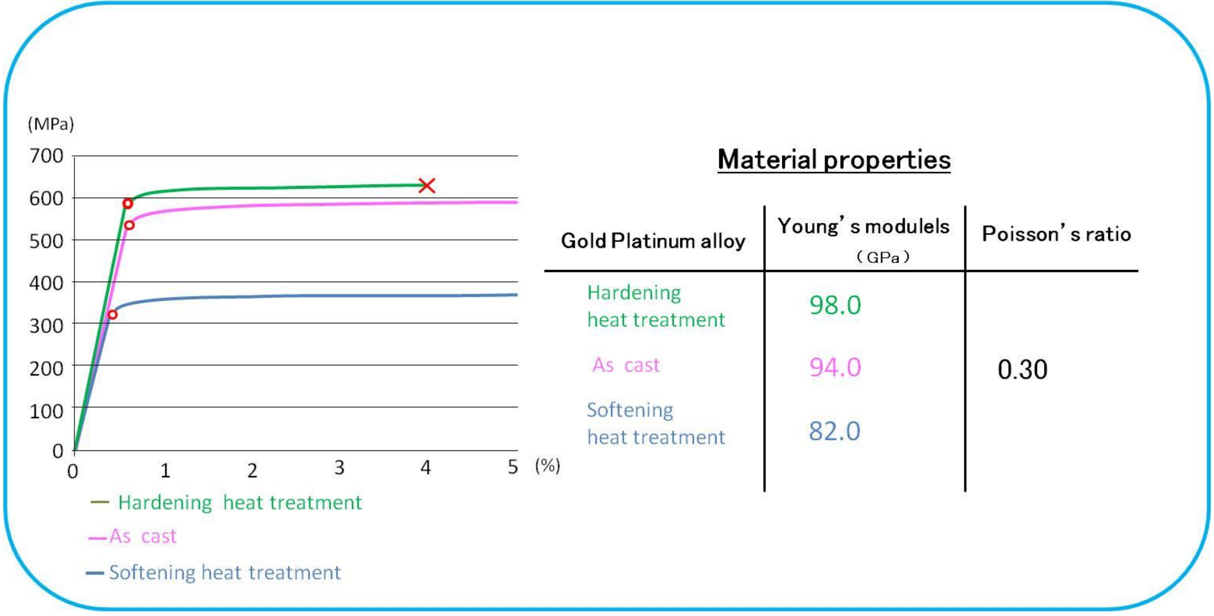
Patran, a general purpose pre/post processor and Mark, a general purpose finite element program, and MSC were used for explanatory and actual analyses.

Results

1. Preliminary experiment

1) Stress-strain curve

Fig. 8 shows the results of stress-strain curves.



Material properties

Gold Platinum alloy	Young' s modulels (GPa)	Poisson' s ratio
Hardening heat treatment	98.0	0.30
As cast	94.0	
Softening heat treatment	82.0	

Fig. 8 Stress strain curves

A known value was substituted. Elastic coefficients were 82 G Pa in hardening heat treatment, 94 G Pa as cast, and 98 G Pa in softening heat treatment. Plastic region remain unchanged for all treatments.

A SEM image (Fig. 9) showed ductile fracture.

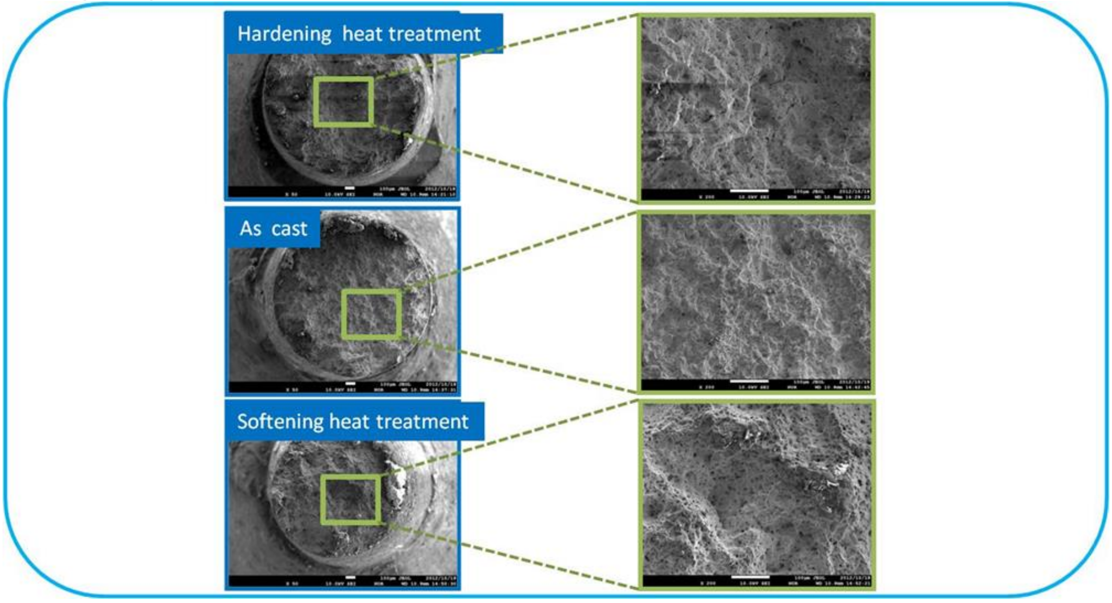


Fig. 9 SEM image

2) Load-displacement curve

Fig. 10 shows the results of load-displacement curves of measurement and analysis values.

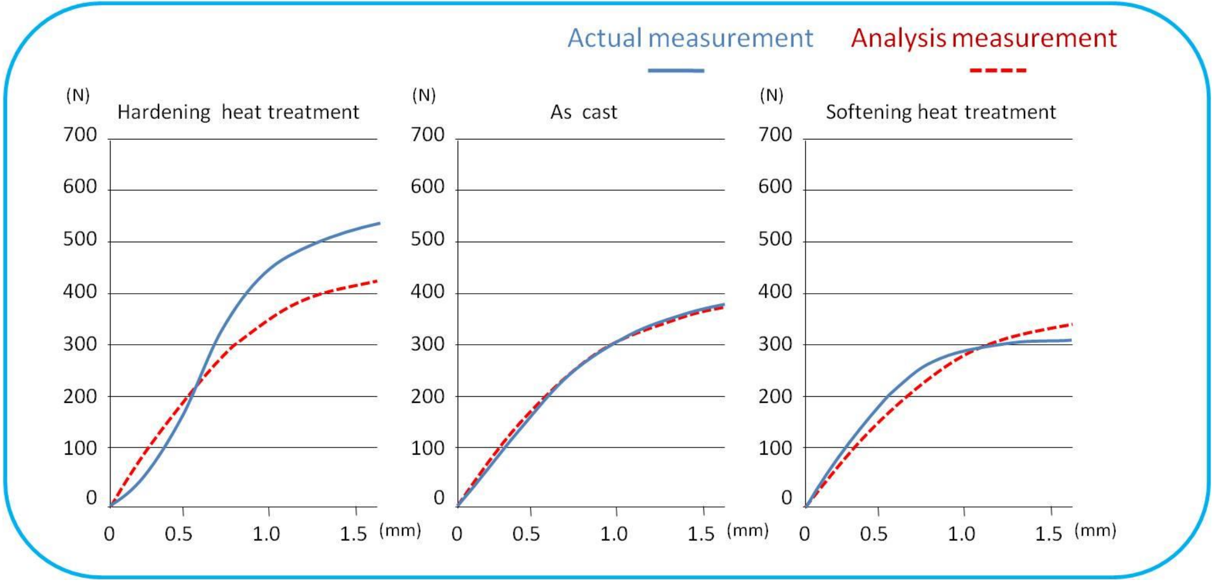


Fig. 10 Load-displacement curves

2. Explanatory analysis

The agreement rate between measurement and analysis values was the highest as cast, followed by softening heat treatment and hardening heat treatment.

3. Actual analysis

Fig. 11 shows the von Mises stress distribution chart of the present analysis.

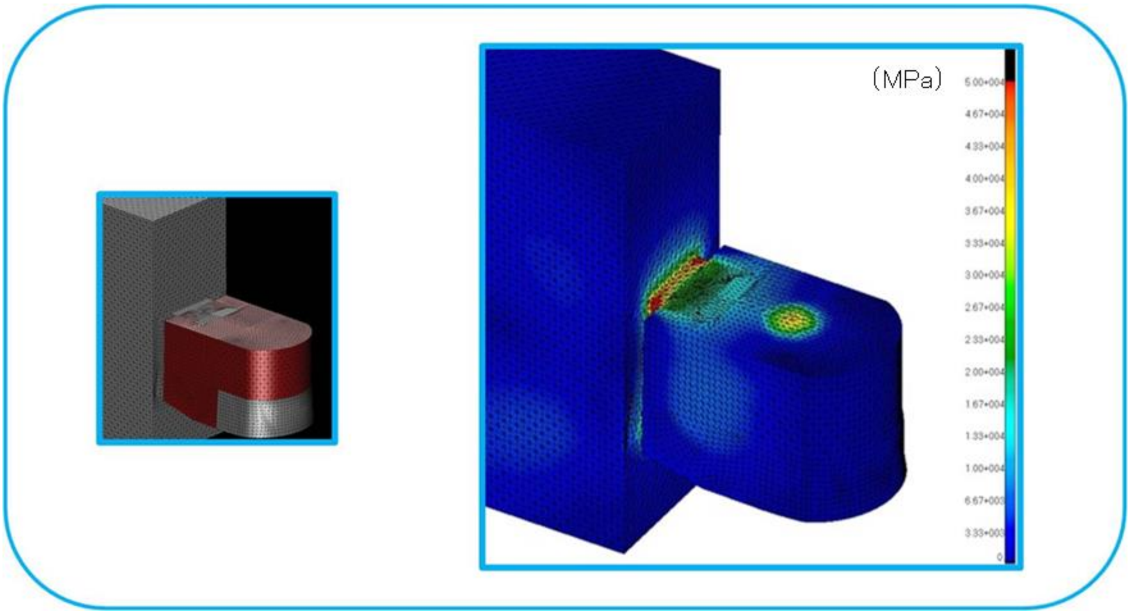
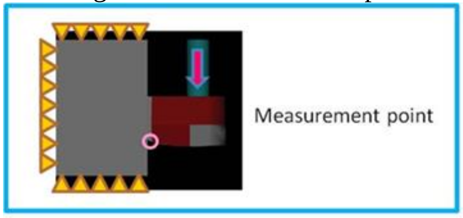


Fig. 11 von Mises stress distribution chart

The stress distribution chart indicated stress concentration of the stress applied on the top surface of an attachment on the neck part of an attachment.

Fig. 12 shows the load-displacement curves of the present analysis.



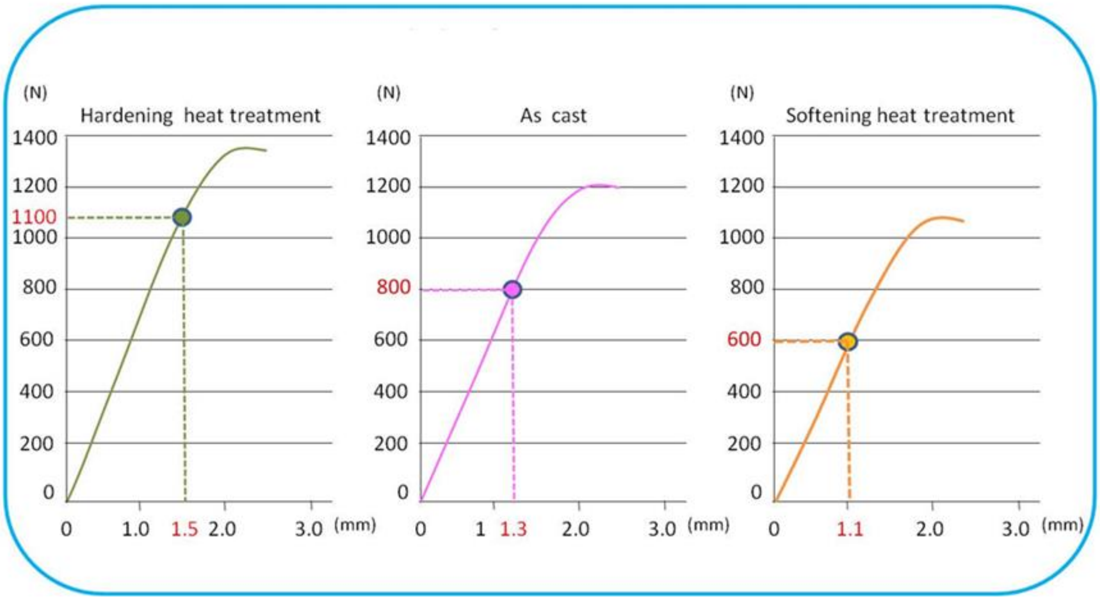


Fig. 12 Load-displacement curves

Elastic limit was 1.5 mm at 1100 N loading for hardening heat treatment, 1.3 mm at 800 N as cast, and 1.1 mm at 600 N loading for soft heat treatment.

Discussion

1. Stress-strain curve

Stress-strain curves were measured using finite element analysis to investigate mechanical strength of an extracoronal magnetic attachment. Actual measurement allowed to know material properties specific to the metal, and to introduce proper mechanical properties to the finite element model. The fracture cross-section after the tensile test was observed by SEM. The images indicated that samples were fractured in a ductile manner, not due to twist or strain by a machine.

2. Preliminary experiment

Although the elasto-plastic analysis is rarely introduced in the medical field, it is actively introduced in the industrial field and its credibility has been established. In the present study, actual measurement of the preliminary experiment and comparison with the explanatory analysis were performed before the analysis of an extracoronal magnetic attachment to confirm practicality and credibility. The results of the preliminary experiment and explanatory analysis showed approximate values in extracoronal magnetic attachments with hardening and softening heat treatment. Errors were confirmed in the actual measurement and analysis values of samples with hardening heat treatment. It is considered that measurement error increased with each heat treatment.

3. Analysis model

A finite element model of the present study was fabricated by constructing an extracoronal attachment model based on the commercialized and normalized CAD data. A housing and the base were fabricated to fit the model. The size of the model was meticulously reproduced.

A model with tetrahedral elements was fabricated. Although it is said that calculation accuracy decreases in tetrahedral elements compared with hexahedral elements, the present model was subdivided to make all elements approximately the same shape, and, therefore, inaccurate stress concentration and reaction force due to the insufficient elements could be avoided.

Stress distribution was evaluated using von Mises stress. Although compression and tensile properties cannot be evaluated in von Mises stress, this method can easily exhibit stress concentration. The results showed stress concentration at the superior margin of an extracoronal magnetic attachment groove, and stress transmission in the upper and lower parts of the base. The similar results were obtained in the break test. Crowns and abutment teeth were simulated for the base. It was pointed out that high stress concentration may arise at the margin line by applying stress to an extracoronal magnetic attachment.

Conclusions

Practicality and credibility were reconfirmed by performing preliminary experiment of elasto-plastic analysis.

Three-dimensional finite element analysis showed that the elastic limit of an extracoronal magnetic attachment fabricated with platinum gold alloy exists around 1,000 N.

References

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