Paper submission

Mechanical Analysis of Extracoronal Magnetic Attachment using Three-dimensional Finite Element Method

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Introduction

Magnetic attachments were originally developed to apply for non-vital teeth. Plastic patterns for extracoronal attachments were developed to expand clinical applications including vital teeth. In clinical setting, a load is indirectly transmitted to the inferior part of extracoronal magnetic attachments through housings with groove joints. Therefore, a load is applied not only to the neck of extracoronal magnetic attachments, but also to grooves and housing joints. Although Shoji from the Department of Removable Prosthodontics, School of Dentistry, Aichi-Gakuin University, reported the results of strength test of extracoronal attachments with housings in 20th Japanese Society of Magnetic Applications in Dentistry, there is no theoretical validation. Our department has performed the elastic stress analysis of extracoronal magnetic attachments. However, the mechanism of plastic deformation remains to be elucidated.

Objective

The purpose of the present study was to investigate the mechanical strength of extracoronal magnetic attachments using a three-dimensional finite element method to compare the results with the actual measurement data. The housing with joints was attached to extracoronal magnetic attachments.

Materials and Methods

Preliminary experiment to verify elastoplastic analysis and main experiment to verify extracoronal magnetic attachment were performed. Analysis models were fabricated for each experiment, and boundary condition and material constant were determined. The procedure is shown below. Patran was used for model fabrication and result display, and a general purpose nonlinear structure analysis solver program (Marc 2008, MSC software) was used for the analysis.

1. Analysis model

    1) Preliminary experiment

        The simple cubic model with a cross-section area of 1.73 x 1.73 mm and 6.11 mm on a side was constructed for the preliminary experiment using Patran. The design and analysis model are shown in Fig. 1.

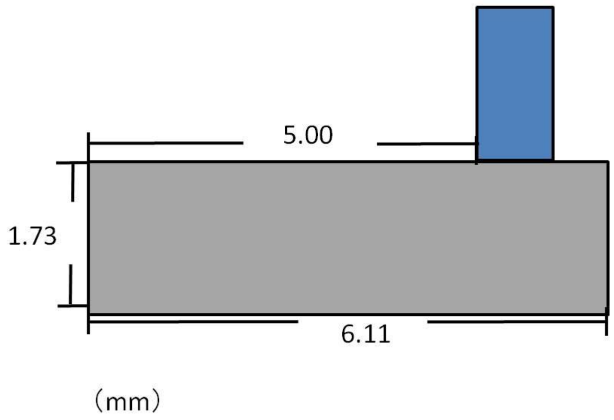


Fig. 1. Preliminary experiment model

2) Main experiment

The 12-mm-high and 9-mm-wide foundation replaced by a natural tooth and an extracoronal magnetic attachment produced from CAD data of the GIGAUSS EC keeper tray were fabricated as a unit, and 2.0-mm-high and 8.6-mm-wide housing was attached on the top. After constructing the foundation and extracoronal magnetic model as a unit, a keeper was cemented, followed by housing placement. Figure 2 shows the design and analysis model.

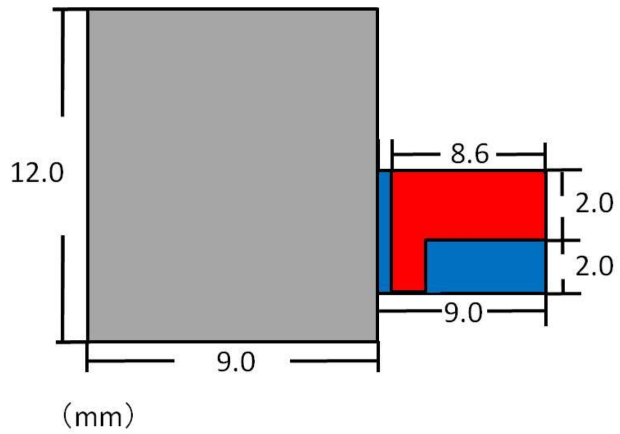


Fig .2. Main experiment model

2. Boundary condition

A complete constraint was applied to the left surface in the X, Y, and Z directions for both preliminary and main experiments as is shown in the figure. For loading condition, a column with 1 mm in diameter was placed on the center of an extracoronal magnetic attachment at 0.5 mm / mm for 15 seconds to apply a load more than 1000 N (Fig. 3).

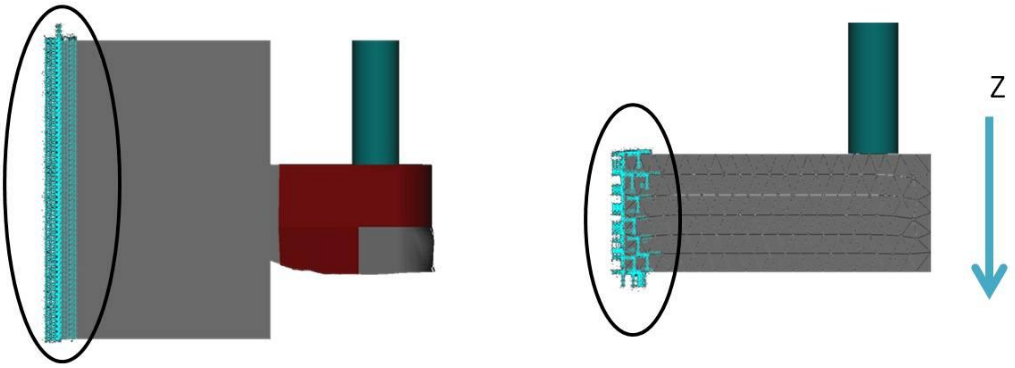
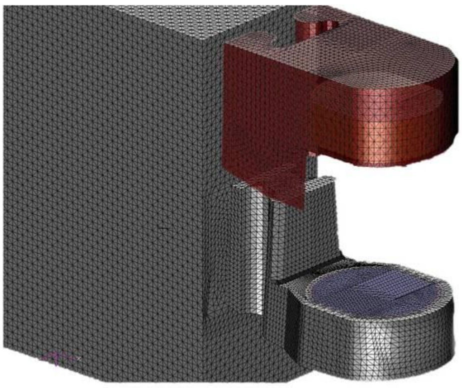


Fig .3. Boundary condition

3. Material constant

The Young’s modulus and Poisson’s ratio were introduced to SUSXM 27, a material of a keeper and a magnet, and cementum. The analysis model of a preliminary experiment, the foundation of the main experiment, and 12Wt% Au-Ag-Pt alloy, a material of an extracoronal magnetic attachment were determined by the stress-strain curve (Fig. 4). Since the material constant of 12Wt% Au-Ag-Pt alloy is unknown in the actual measurement data, hardening and softening heat treatment stress-strain curves were introduced to reproduce elasto-plasticity.

Elastic deformation after each heat treatment was calculated from the linear part of the graph, and Young’s modulus 12,987 was introduced. An arbitrary figure in the graph was introduced after plastic deformation for reproduction (Fig. 5).



	Young’s modulus (MPa)	Poisson’s ratio
12Wt% Au-Ag-Pt alloy	determined by the stress-strain curve	
SUSXM27	196,000	0 . 30
cementum	8,820	0 . 30

Fig .4. Material Properties

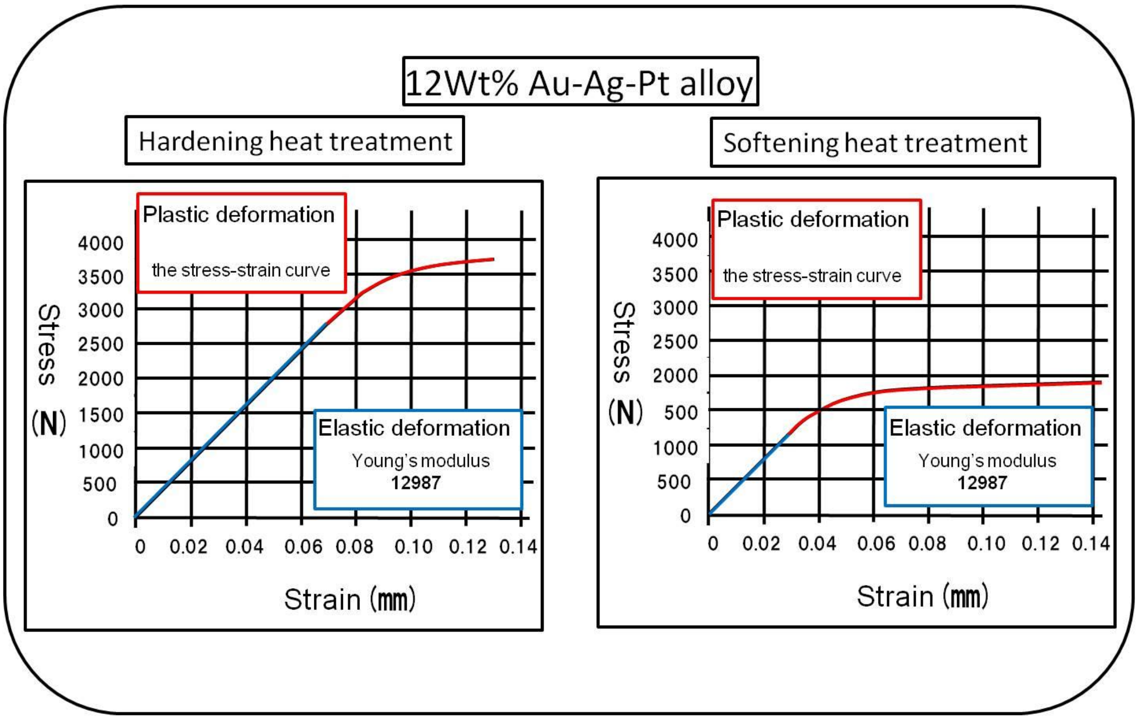


Fig .5. Hardening and softening heat treatment stress-strain curves
(12Wt% Au-Ag-Pt alloy)

Results

1. Preliminary experiment

Verification of elasto-plastic analysis was performed by actual measurement and load displacement curve. The figure shows a load displacement curve. The X axis stands for the z axis displacement of the preliminary experiment analysis model, and the Y axis stands for the stress value applied on the test sample of the preliminary experiment. Values in the load displacement curve after hardening and softening heat treatment of the metal were approximated the actual measurements (Fig. 6).

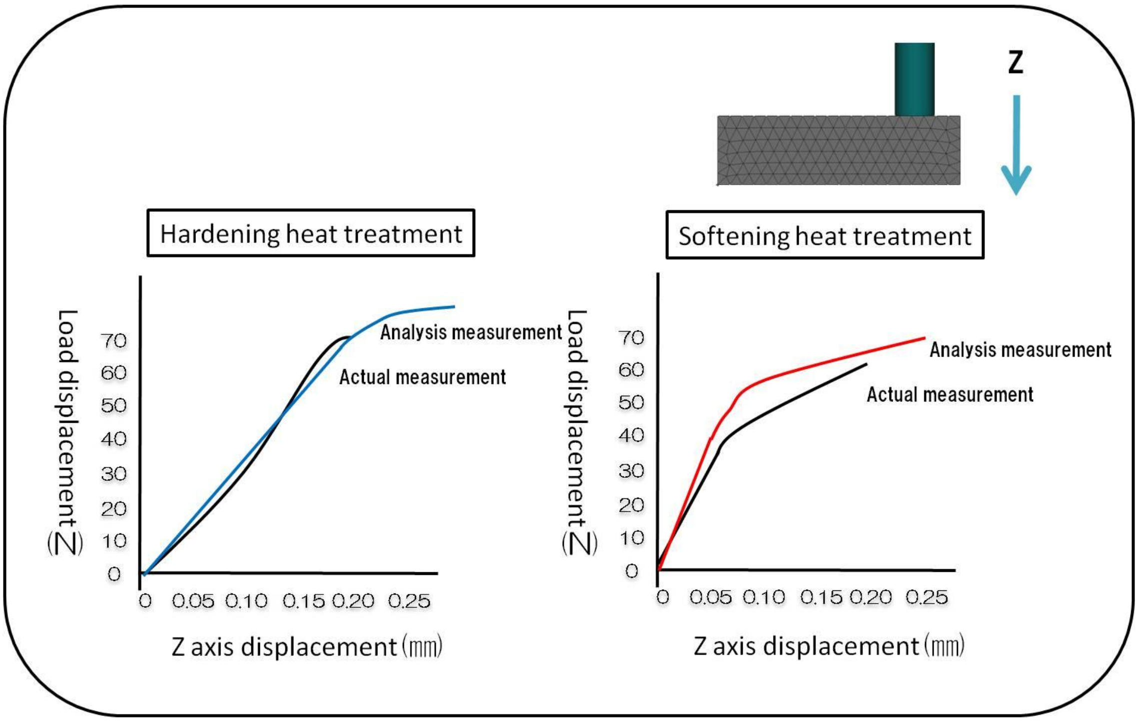


Fig .6. Actual measurement and load displacement curve

2. Main experiment

1) Stress distribution

Stress distribution was evaluated using von Mises stress. Stress concentration was observed in the upper margin of the extracoronal attachment groove. The result confirmed that stress is transmitted to the upper and lower margins of foundation (Fig. 7).

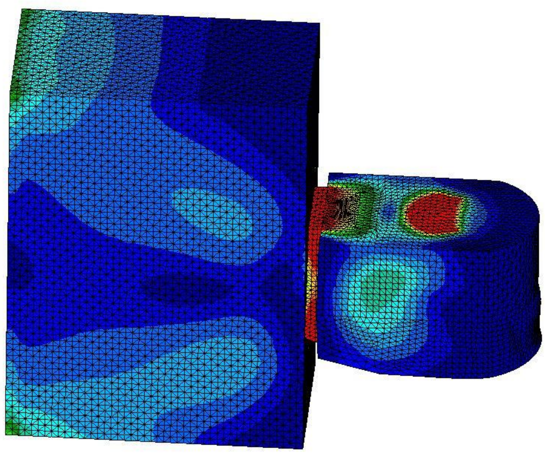


Fig .7. Stress distribution

2) Load displacement curve

The horizontal axis of the load displacement curve shows z axis displacement of an extracoronal magnetic attachment, and the vertical axis shows a load in the measurement point shown in the slide.
The result confirmed that plastic deformation occurs over 733 N in the hardening heat treatment and over 390 N in the softening heat treatment (Fig. 8).

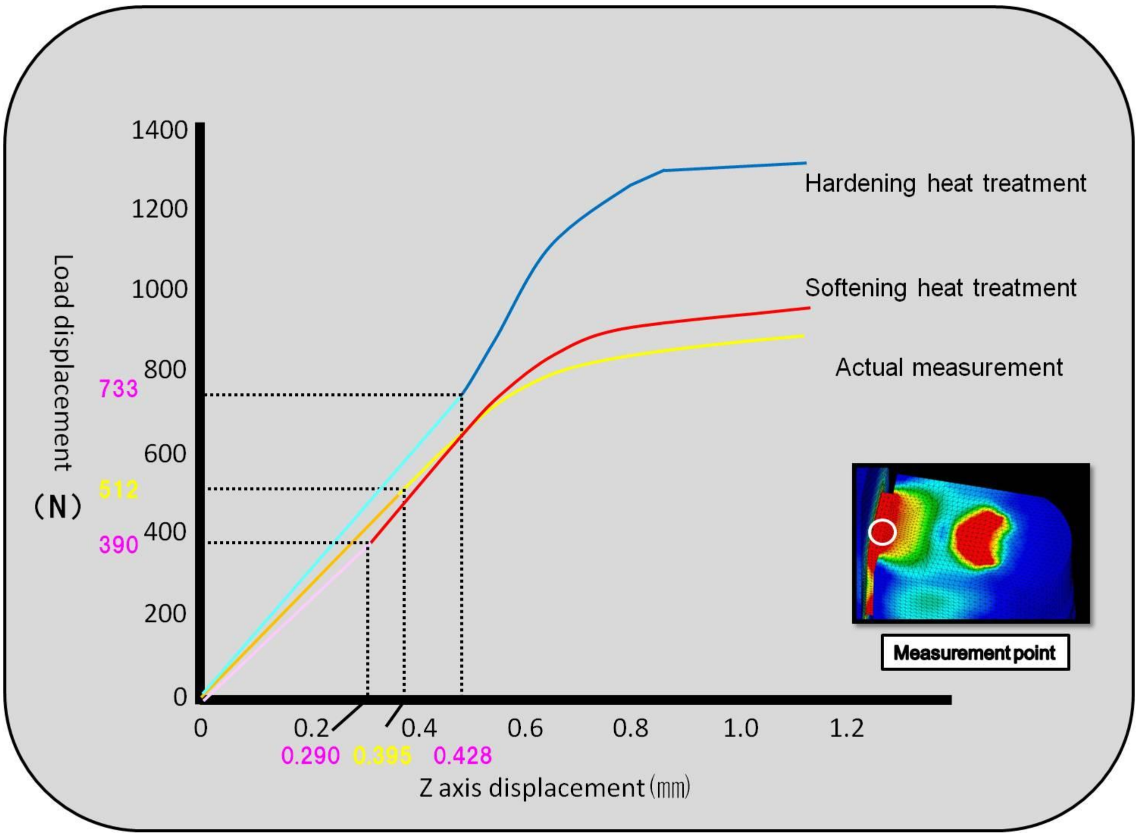


Fig .8. Load displacement curve

Discussions

1. Analysis model

The finite element model used in the main experiment was fabricated by constructing extracoronal attachment model based on the practically-used and normalized CAD data, and a housing and foundation were fabricated to fit the model. Since the size of the model is accurately reproduced, problems are unlikely to happen.
The model was fabricated using tetrahedral element. Although the calculation accuracy of the tetrahedral element is considered to be not as good as hexahedral element, the fabricated model in the present study was segmentalized so that the element figure is approximated as hexahedral element. Therefore, inaccurate stress concentration and

reaction force due to insufficient element could be avoided.

2. Boundary conditions

The same boundary conditions as the strength test of the 20th Conference of Japanese Society of Magnetic Applications in Dentistry were used in the present study. A load up to 1000 N was applied at 0.1 mm / sec. The results approximated the actual measurement were obtained by specifically setting the speed and acceleration. However, there was a difference in the metering rod between actual measurement and the analysis. This is considered to be due to the fact that the tip of the metering rod is round in the actual measurement and flat in the analysis. Further discussion is necessary to understand the influence of this difference.

3. Elasto-plastic analysis

Although elasto-plastic analysis is barely used in dentistry, it is widely introduced in the industrial field and gains credibility. In the present study, a preliminary experiment was performed to reconfirm the credibility.

4. Metal treatment

Mechanical properties of the hardening and softening heat treatments were used for 12Wt% Au-Ag-Pt alloy. Although cast strength was measured in the actual measurement, normalized mechanical properties were applied in the present study. This is due to the fact that cast strength is not consistent, and, therefore it was considered inappropriate to use for simulation.

5. Analysis result

The graph obtained by the preliminary analysis approximated the actual measurement graph. The result suggested that validity of the elasto-plastic analysis using three-dimensional finite element method was confirmed. Since the main experiment introduced the same condition setting, the validity of the main experiment was also considered satisfactory. Actual measurement and analysis values did not completely agree. This was considered to be the influence of displacement in XY axis direction in actual measurement.

In the present study, evaluation was performed using stress distribution and load displacement curve.

Stress distribution was evaluated using the von Mises stress. Although the von Mises stress cannot be used for compression and tension evaluations, it indicates stress concentration easily. The results showed stress concentration in the upper margin of the extracoronal attachment groove, and stress transmission to the upper and lower margins of foundation. The similar results were obtained in the break test of actual measurement. A crown and an abutment tooth were assumed for the foundation, and high stress concentration was expected in the margin line by receiving a stress in an extracoronal magnetic attachment. The same condition setting as the preliminary experiment was applied in the load displacement curve, and the results were compared and discussed with actual measurement of the extracoronal magnetic attachment strength test by Shoji from the First Department of Prosthodontics, School of Dentistry, Aichi-Gakuin University. The actual measurement was performed during casting. The actual elastic limit was 512 N. This value was in between softening and hardening heat treatment values. The same results were reported by Hideo Nakamura, and therefore, the validity of the present analysis was confirmed. However, a load displacement curve of the softening and hardening heat treatment had multiple curves instead of two. This is considered to be due to the element influence after segmentation. It is necessary to raise the precision by using hexahedral element with multiple nodal points and increasing contact points.

Conclusions

The results of the elasto-plastic analysis confirmed that an extracoronal magnetic attachment has wide elastic area as actual measurements. Analytical values demonstrated that deformation does not occur until 733 N in the hardening heat treatment, and 390 N in the softening heat treatment.

References

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2) H. Nakamura: An Influence of Heat Treatment on Fatigue Strength of Au-Ag-Pd Cast, Dental Materials Journal, 16 (2) 141 154, 1997