Studying the effect of the circumferential clasp arm design on stress distribution using three-dimensional finite element analysis

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Abstract

High stresses which result during functions in the cast clasps arms are the main causes of deformations or fractures. The purpose of the study was to evaluate the stress distribution in three-dimensional finite element analysis models of clasps and to select their preferable design.

A three-dimensional finite element analysis was used for the investigations. Preformed clasp wax patterns for circumferential clasps were selected and three parameters namely length, thickness and width at the base and tip were measured to generate purposely designed experimental three-dimensional models. Generated stresses and deformatioans were calculated numerically and plotted graphically.

Within the limitations of this study, the preferable cross-sectional shape of the retentive cast circumferential clasp arm was determined as half-round and the taper 0.6 mm.

the ideal cross section of the retentive clasp arm was half round with 0.6mm taper diameter.

Key words: circumferential clasp design, stress distribution, finite element analysis.

Introduction

Retention force and stress distribution in the clasp arms are the keys for a long-term success of removable partial dentures.[1] It has been recognized that the three factors[2] that affect the design of the clasp arms are clasp material, clasp form and amount of undercut, respectively. Among this, only the clasp form is controlled by the dentist or dental technician. The mechanical properties of the clasp material are normally determined by the alloy to be used, commonly a cobalt-chromium alloy. The needed undercut for circumferential clasps is 0.25 mm.[2,3] After clinical evaluation of conventional removable partial dentures, the complication and failure rates are high at the retainers and about half of them usually are replaced after 5-6 years.[4,5] Therefore the most studied components of these dentures are the cast clasps. The first finite element analyses for the investigation of the dimensions, shape and stresses in clasps were two-dimensional [6,7] Various retainer designs were compared by measuring the occlusal load,[8] the stress distribution in the abutments and the abutment mobility,[9,10] as well as the Masticatory performance of the dentures.[11]

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Other studies suggested basic principles for optimizing the design of different clasp components, like the occlusal rests.[12] Comparative studies were made for alternative materials to Co-Cr for removable partial dentures applications like titanium and noble alloys.[13-16] Using the finite element analysis, the clasp should be designed with consideration of the stresses distributions within the clasps.[17] The purpose of the study was to evaluate the stress in a three-dimensional finite element analysis model of clasps with different cross-sectional shapes, tapers and thickness/width ratios. Therefore achieving clasp arm design producing less stress is very important. and later three-dimensional.

Materials and Method

Different preformed clasp wax patterns for circumferential clasps (Fino, Degussa) were selected and taken as models (Fig.1). Selected parameters of the clasp arms to be measured were the length, thickness at the base (G_1) and tip (G_2) and width at the base (L_1) and tip (L_2) shown in Figure 1.

Purposely designed experimental three-dimensional models were constructed using the following parameters: L_2/L_1 = 0.4; 0.6 and 0.8; G/L = 0.4; 0.5, and 0.6; L_1 = 2 mm, 2.2 mm and 2.4 mm, respectively. The length was maintained constant, having a value of 12 mm. After these combinations, 27 geometrical models resulted (Table 1).

Three-dimensional finite element analysis software (ANSYS version 6) was used for the structural simulations. The finite element models were constructed and subdivided into 1500 solid eight - node elements, connected at 1736 nodes. In making the finite element models, the characteristics of the Co-Cr alloy (Wironium®, Bego, Bremen, Germany) used for the cast clasps were entered into the computer program: tensile strength- 940 MPa; ductile yield - 640 MPa; modulus of elasticity - 2.2 x 10^5 MPa; Vickers hardness - 360 HV; Poisson's ratio - 0.3. All nodes at the base of the clasps were restrained in all directions and a concentrated load of 5 N was applied at the inner tip of the clasp arm.

The generated stresses and deformations were calculated numerically and plotted graphically. Results were displayed as colored stress or deformation contour plots to identify regions of different stress concentrations or deformations.

Results

Figures 2 - 7 illustrate the von Mises equivalent stress and the deformations for the first three cases. High stress values were present on the outer surface of the clasp arms and for the thicker arm, the stress surface was smaller and was near the clasp tip. The deformations were maximal at the tip in all cases. Only the values were different. The correlations between the calculated maximal stress and deformation allow the selection of the preferable parameters of a clasp arm (Figs. 8 and 9).

Discussion

The results indicated that the ideal parameters of the clasp arm, for a deformation of 0.25 mm are the ratios L_2/L_1 = 0.6 mm and G/L = 0.5 mm. This means that the ideal cross-sectional shape should be half-round. For example, the dimensions can be: length = 12 mm, width at the base L_1 = 2 mm, width at the tip L_2 = 1.2 mm, thickness at the base G_1 = 1 mm, thickness at the tip G_2 = 0.6 mm. It appears as if in a more rigid clasp, the stresses are concentrated. The investigations of this study indicated the preferable cross-sectional shape and taper of cast circumferential clasp arms. It was observed that decreasing the thickness of the arms, without variation of the other parameters, the maximal stresses moved closer to the tip. Also, decreasing the taper, without variation of the other parameters, the maximal stresses moved closer to the base of the clasp arms. Because of the various kinds of clasp patterns commercially available, their selection in practice is very difficult. In clinical use the clasp arms may be chosen within the limits of the real conditions, but a design producing less stress is the most important parameter. Several studies investigated different aspects of the clasp design in relation to their retention and usage. Sato *et al.*[10] clarified the complications and failures of the clasps, direct retainers of removable partial dentures.

Regarding the circumferential clasp arm forms (cross-sectional form and taper), Sato *et al.*[2] stated that clasp arms with thinner and wider dimensions and with the taper of 0.8 mm showed less stress. Other findings[1] showed the effect of the vertical curvature on the stress and flexibility of the clasp arms. For the I-bar clasps Sato *et al.*[6,7] suggested the preferable shape as biomechanical point of view.

The studies of Bridgeman *et al.*[13] and Rodrigues *et al.*[14] investigated clasps of different alloys and suggested that titanium and titanium alloys are suitable materials for cast clasps, but these have lower retention than those made by cobalt-chromium alloys. Vallittu and Kokkonen[16] suggested that significant differences exist in the fatigue resistance of removable denture clasps of different alloys, which may cause loss of retention of the removable partial denture and clasp failure.

To evaluate the influence of the clasps on the abutments, the stress distribution for these and the teeth mobility was observed in relation with different retainers.[4,9]

Conclusions

From the findings of the present research, the following observations were made:

- The three-dimensional finite element analysis allowed the investigation of the preferable design for the retentive cast circumferential clasp arms.
- The ideal cross-sectional shape of the retentive cast circumferential clasp arm was half-round.
- Preformed clasp-patterns with a taper of 0.6 mm should be preferable for the long-term use of the retentive cast circumferential clasp arms.

References

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Table 1. Parameters of the designed experimental three-dimensional models (L1 = width at the base, L2 = width at the tip, G/L = ratio between thickness and width)

Case	L_1	L_2/L_1	G/L
1	2	0.4	0.4
2	2	0.4	0.5
3	2	0.4	0.6
4	2	0.6	0.4
5	2	0.6	0.5
6	2	0.6	0.6
7	2	0.8	0.4
8	2	0.8	0.5
9	2	0.8	0.6
10	1.8	0.4	0.4
11	1.8	0.4	0.5
12	1.8	0.4	0.6
13	1.8	0.6	0.4
14	1.8	0.6	0.5
15	1.8	0.6	0.6
16	1.8	0.8	0.4
17	1.8	0.8	0.5
18	1.8	0.8	0.6
19	1.6	0.4	0.4
20	1.6	0.4	0.5
21	1.6	0.4	0.6
22	1.6	0.6	0.4
23	1.6	0.6	0.5
24	1.6	0.6	0.6
25	1.6	0.8	0.4
26	1.6	0.8	0.5
27	1.6	0.8	0.6

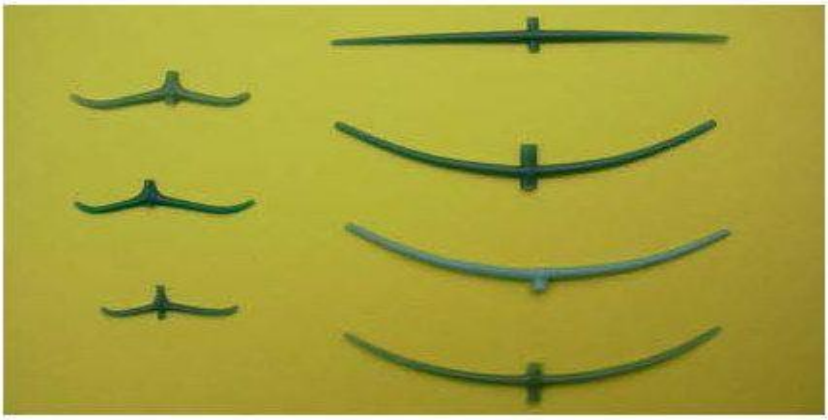

Fig. 1. Preformed clasp wax patterns for circumferential cast clasps.

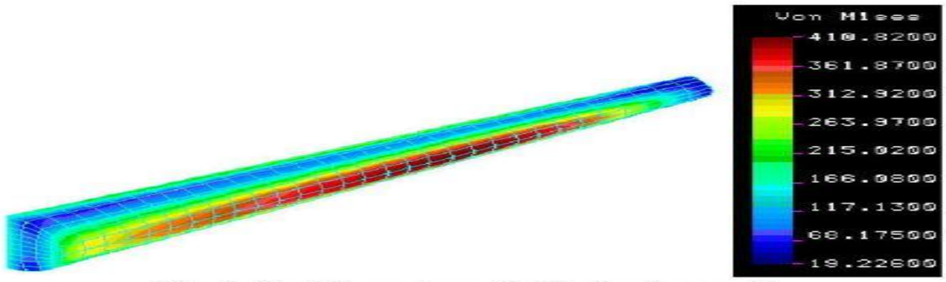

Fig. 4. Von Mises stress distribution in case 2.

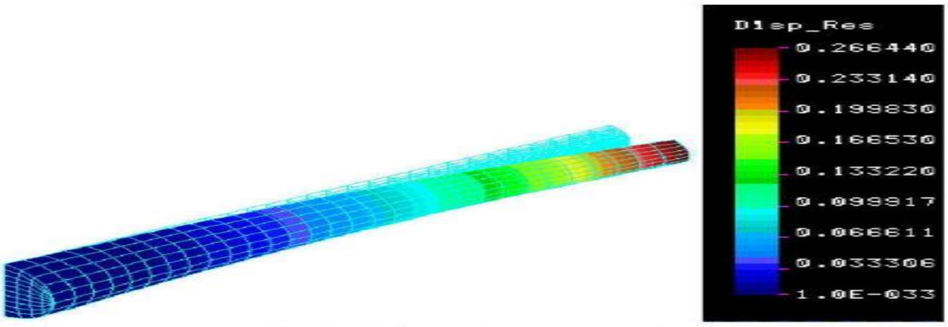

Fig. 5. Deformations in case 2.

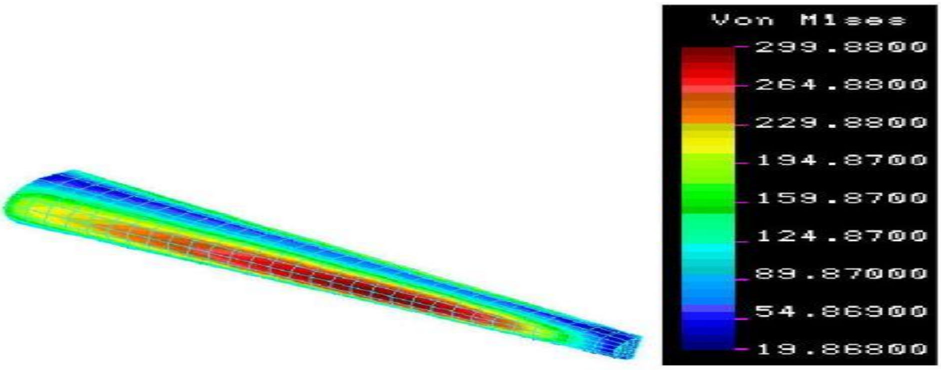

Fig. 6. Von Mises stress distribution in case 3.

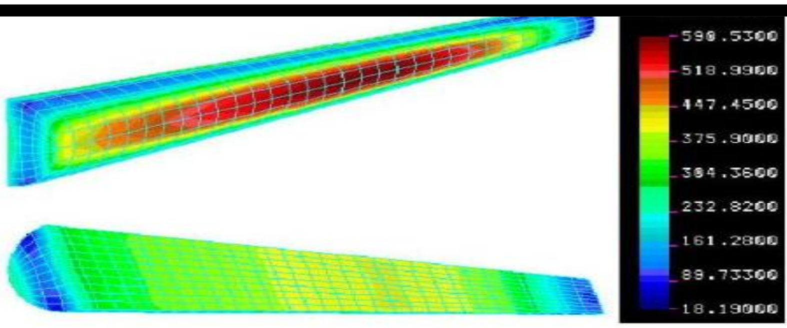

Fig. 2. Von Mises stress distribution in case1 (outer and inner surface of the clasp arm).

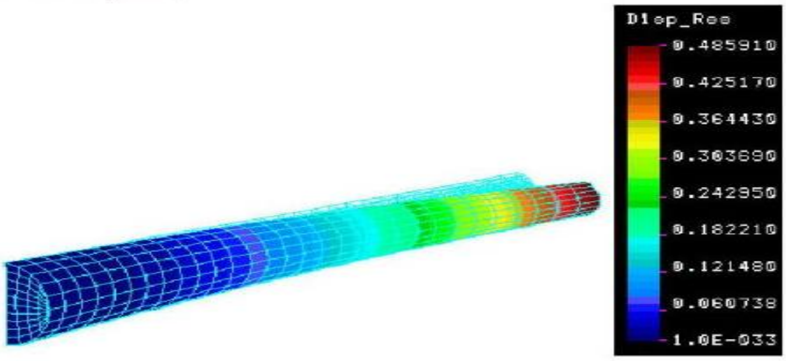

Fig. 3. Deformations in case 1.

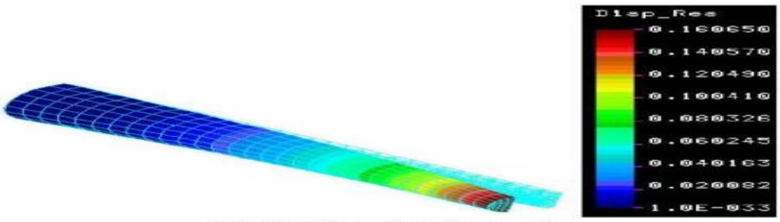

Fig. 7. Deformations in case 3.

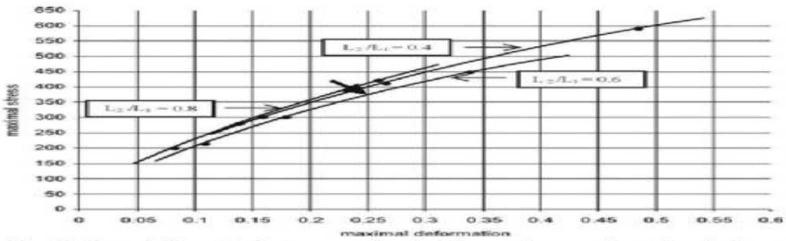

Fig. 8. Correlations between maximal deformation and maximal stress for L_2/L_1 = constant.

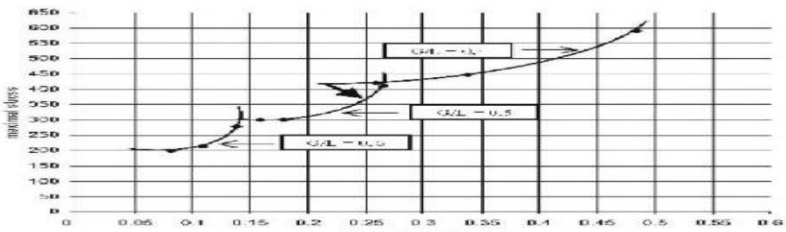

Fig. 9. Correlations between maximal deformation and maximal stress for G/L = constant.