Metal ceramic fixed partial denture - fracture resistance

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ABSTRACT: Metal ceramic fixed partial dentures (FPD) are suitable to increase fracture resistance presenting higher clinical longevity. This type of prosthesis is mainly used when a great number of teeth replacements are needed. The FPD under analysis is defined by a metallic infrastructure (titanium) and by a ceramic coating. The advantages of hybrid FPD lie in their predictable biomechanical behaviour, versatility and cost. The main disadvantage is related to aesthetic functionality. Karlsson (1986), Lindquist & Karlsson (1998) and Palmqvist (1993) quantified the life time for hybrid FPD, referring 10 years in service to be a survival of break point. The connector design is of great importance to improve smooth stress pattern in the region between teeth. This region is also restrained by biological and aesthetic reasons. Ceramic material presents elevated failure rate in FPD due to brittleness. This work intends to predict fracture resistance to different loading conditions, using a smeared fracture approach (continuous damage mechanics). Results agree well with experimental evidence.

1 INTRODUCTION

Despite the increase of all-ceramic fixed partial dentures, metal ceramic units continue to be used due to their clinical durability and biocompatibility. Ceramic fractures represent serious and costly problems in dentistry. Moreover, they pose an aesthetic and functional dilemma both for the patient and the dentist, Özcan (2003).

Considering the existence of two or more different materials, with different biomechanical properties (thermal and mechanical) and also the adherence between them (bond strength), it is expectable to foresee problems under clinical conditions.

Failure of the restoration is dependent on different several factors. Optimum clinical design should require knowledge of failure mechanism. Besides the previous mentioned factors affecting failure, adverse environmental conditions, such as moisture and other fluids may also contribute to decrease life of FPD. The presence of microcracks at surface should be the most important reason for ceramic failure, besides the existence of pores inside ceramic material.

This paper intends to analyze the brittle behaviour of ceramic material used on fixed partial dentures, using the concept of continuous damage mechanics. In this concept, the smear of a crack or crush is predicted by the stress level determined by tension or compression, maintaining the continuity of the displacement field where the material became ineffective.

A three unit FPD consisting of two piles and a supported tooth is analyzed, when subjected to three different loading conditions over the pontic area on the top region of crown (L1 - load type one considered as two point load at the cusps zone, L2 - load type two considered as ring load at the top zone and L3 - load type three considered as one point load located in the fossa zone), see figure 1.

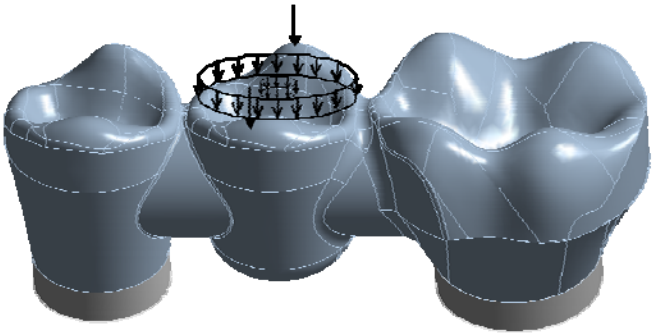

Figure 1. Three unit FPD and loading conditions, (L1, L2, L3).

All loads were applied orthogonal to the occlusal plane, using incremental procedure to predict smeared cracking and crushing.

The three unit FPD is made of a metallic infrastructure (titanium) and a ceramic coating, assuming perfect contact between them.

2 OBJECTIVES

The objective of this research is to predict damage on ceramic material, depending on load type and level. An incremental loading step was applied until the maximum load bearing was reached for each loading condition. Those different loading condition should represent a wide range of dally situations. The pattern of cracking and crushing should be determined. Cracking is the ultimate state condition under tension while crushing is represented by compressive stress state.

3 MATERIALS

Two different materials should be defined for numerical simulation of this metal-ceramic partial fixed denture. The adherence between them is not considered in this investigation, assuming perfect contact between both. The ceramic material should be considered as brittle, using adequate constitutive relations and the titanium should be considered as normal ductile metallic behaviour.

Ceramic present higher strength resistance in compression than in tension. Figure 2 represents the mechanical behaviour under uniaxial stress conditions, being the material capable of stress relieving under tension stress. This behaviour is normally used to increase numerical convergence.

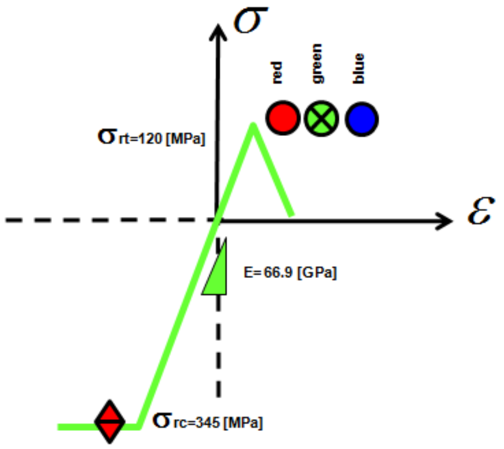

Figure 2. Stress – strain relation for ceramic material.

Material may undergo plastic behaviour under compression. Table 1 represents the material properties used together with failure mechanism, based on Willam and Warnke (1975) criteria.

Table 1. Material model for ceramic material.

MODEL	PROPERTY / FUNCTION	VALUE
Linear (tension/compression)	Elastic modulus	66.9 [GPa]
	Poisson coefficient	0.29
Non – linear (compression)	Strain	Stress
	0	0
	0.005156	345 [MPa]
	0.010000	345 [MPa]
Failure model	Shear transfer coef. (open crack)	0.25
	Shear transfer coef. (closed crack)	0.90
	Tensile cracking stress	120 [MPa]
	Compressive crushing stress.	345 [MPa]
	Stiffness mult. for cracked tensile	1

Titanium alloy is considered as ductile material, which means that material presents linear elastic and may undergo plastic deformation, under tension and compression, see figure 3. Strain values for ultimate stress may present values close to 20 %.

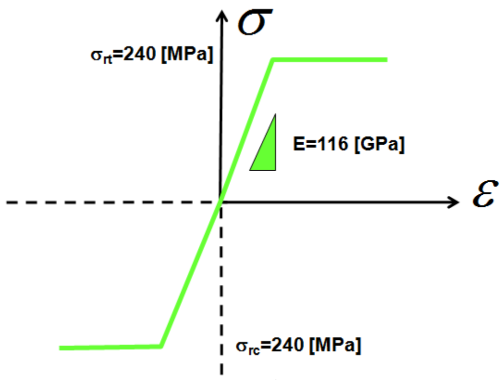

Figure 3. Stress – strain relation for titanium.

Table 2 represents the mechanical material properties for tension and compression of titanium.

Table 2. Material model for titanium alloy material.

MODEL	PROPERTY / FUNCTION	VALUE
Linear (ten. / compr.)	Elastic modulus	116 [GPa]
	Poisson coefficient	0.34
Non – linear (tension / compression)	Strain	Stress
	0	0
	0.002068	240 [MPa]
	0.200000	240 [MPa]

4 METHODS OF ANALYSIS

The geometry of this fixed partial denture was defined as parasolid format in Solidworks CAD software and then fully transferred to the analysis ANSYS software. The geometry is mathematically modified to finite solid 65 and solid 45 elements to represent ceramic and metallic material, respectively, see figure 4.

The metal infrastructure is a bridge in cantilever supporting condition.

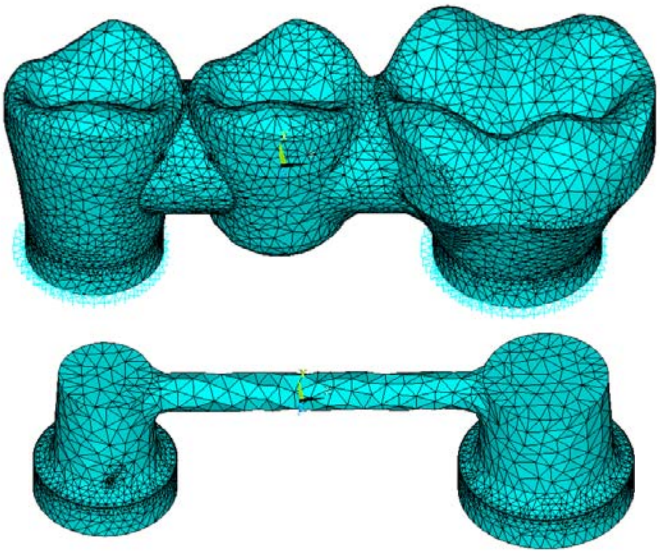

Figure 4. Unstructured finite element mesh with tetrahedrons. Complete mesh and metallic infrastructure.

Solid 65 is a three dimensional finite element with eight nodes and eight integration points, with three degrees of freedom at each node (translations in the nodal x, y, and z directions). The most important feature of this element is that it can represent both linear and non-linear behaviour of the ceramics. For the linear stage, the ceramics is assumed to be an isotropic material up to cracking. For the non-linear part, the ceramics may undergo plasticity. Cracking may take place up to three orthogonal directions at each integration point. A crack may be developed in one plane and if subsequent tangential stress to the crack face are large enough, a second (or third) crack may also be developed (red, green and blue color circle outline), see figure 5. If the crack has opened and then closed, the circle outline will have an X through it.

Cracking is assumed to be spatially distributed over entire volume of element or volume attached to each integration point. The presence of a crack at an integration point is represented through modification of the stress-strain relations by introducing a plane of weakness in a direction normal to the crack face.

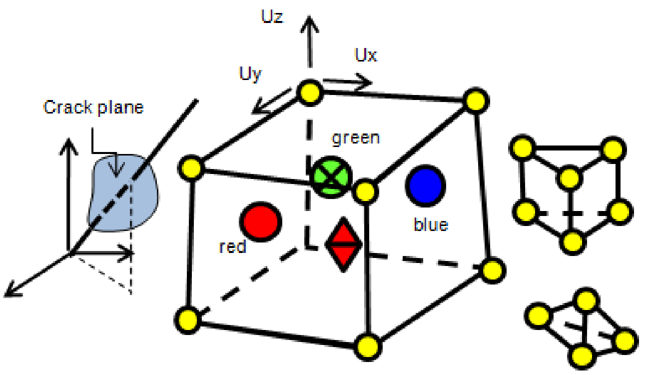

Figure 5. Finite Solid 65 element.

If the material fails at an integration point during uniaxial, biaxial, or triaxial compression, the material is assumed to crush at that point. In Solid 65, crushing is defined as the complete deterioration of the structural integrity of the material and represented by an octahedron outline. Under conditions where crushing has occurred, material strength is assumed to have degraded to an extent such that the contribution to the stiffness of an element, at the integration point in question, can be ignored.

Solid 45 is a three dimensional finite element with almost the same characteristics as mentioned except for predicting cracking and crushing.

5 RESULTS

Load bearing resistance was determined for each loading condition. Table 3 resumes the ultimate load for support equilibrium. After that load level it is no longer possible to sustain equilibrium and the 3 unit FPD is considered damaged.

Table 3. Fracture resistance.

LOADING	ULTIMATE LOAD
L1	128 [N]
L2	201 [N]
L3	514 [N]

Progressive degradation lead to crack initiation and growth, as represented in figures 6-8.

For load case L1, cracking is initiated next to the loading zone (cusps) and progressive damage also stars at the bottom of the abutments, in the neighbourhood to the bottom ceramic material.

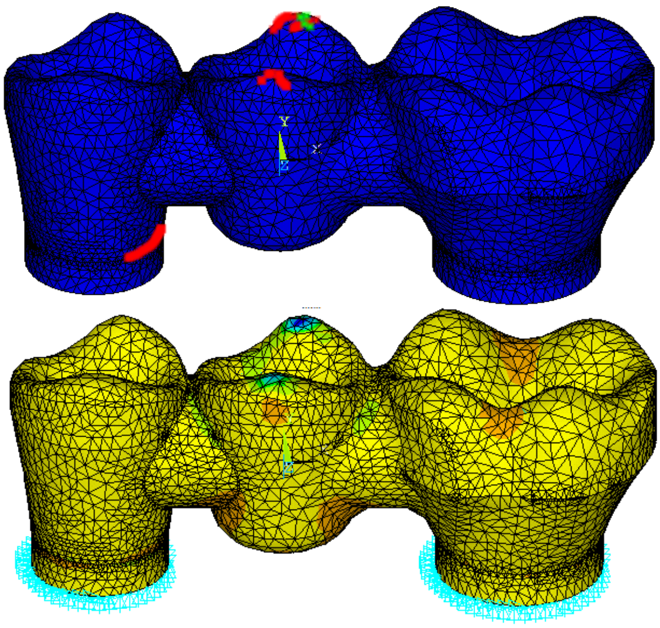

Figure 6. Ultimate limit state condition of FPD to load type 1 – LT1. Fracture prediction and longitudinal stress field.

The stress field is strongly dependent on fracture prediction, because material is losing resistance near cracks and crushed ceramic material.

For Load case L2, cracking is initiated next to the left abutment with progressive damage in the neighbourhood to the bottom ceramic material.

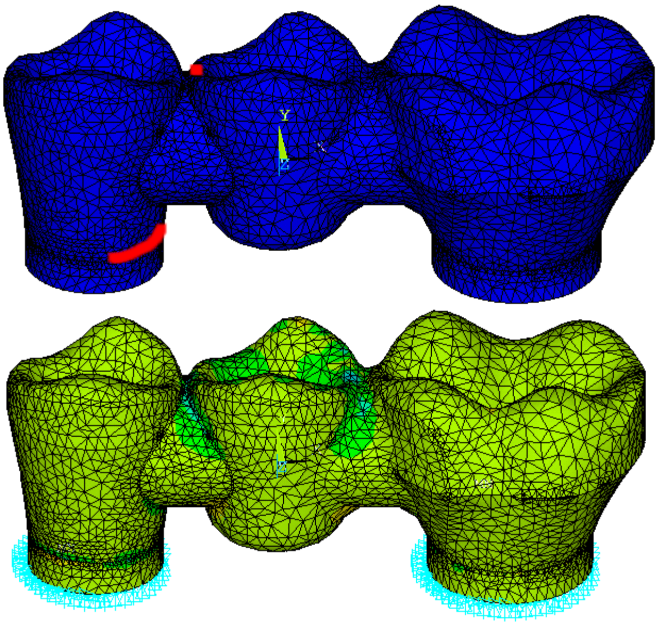

Figure 7. Ultimate limit state condition of FPD to load type 2 – LT2. Fracture prediction and longitudinal stress field.

The stress field is similar to the resultant stress field for load case L1, and is also dependent on fracture progressive damage.

For Load case L3, cracking in initiated at the bottom of the abutments, with progressive collapse in the loading zone and also in the connecting bridge element, which represents traditional collapsing mode, as reported by different authors, Tsumita et al (2007).

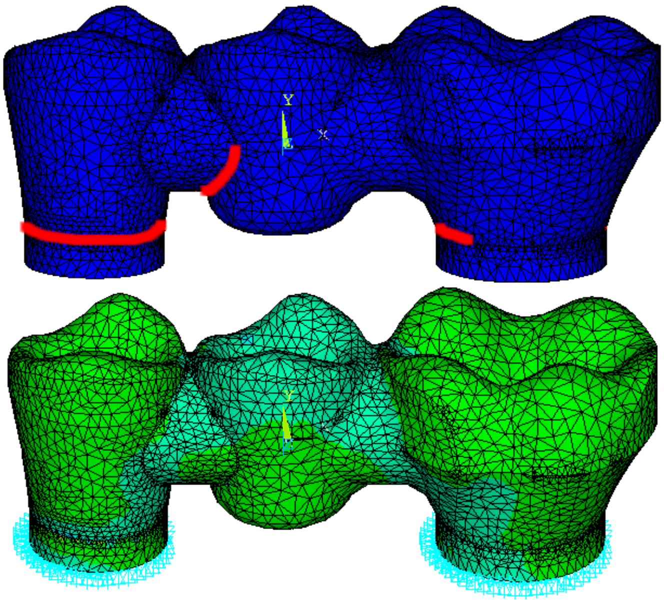

Figure 8. Ultimate limit state condition of FPD to load type 3 – LT3. Fracture prediction and longitudinal stress field.

The stress field presents two well defined compressive and tensile zones.

The connection bridge presents different design near central tooth (pontic). The rounded shape on the right contrast with the sharp geometry on the left, which is responsible for increasing the stress level and simultaneously with progressive failure.

6 CONCLUSIONS

There is consistent epidemiological evidence that mechanical failure of a dental prosthesis occurs after a certain number of service years. In case of prosthodontic restoration, ceramics cannot be added intraorally due to processing conditions. Replacement of a failed fixed partial denture is not a pratical solution, reason why this type of prothesis should be carefully design for maximum life cycle, Özcan (2003).

The most frequent reasons for ceramic failures are related to progressive cracking. Sharp shape geometry should be avoided to decrease maximum stress level.

Three different loading conditions were tested, leading to different fracture resistance. Load case L1 presented smaller fracture resistance due to localized effect of the applied force. Progressive collapsing near the abutment was revealed. Load case L2 presented higher fracture resistance, but failure occurred in the same location as load L1. This is mainly due to the similar resultant stress field. Load case L3 revealed maximum fracture resistance, with typical collapsing mode.

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