Numerical study of the behavior of a Zirconia dental prosthesis with prior defect

Article *in* Journal of the Serbian Society for Computational Mechanics · January 2017

DOI: 10.24874/jsscm.2017.11.01.01

3 authors:

Meddour Belkacem
Unversity Abbas Laghrour

Faicel Khadraoui
Abbes Laghrour - Khenchela University

amal Guerraoui
University of Batna 1

Journal of the Serbian Society for Computational Mechanics / Vol. 11 / No. 1, 2017 / pp 1-10
(DOI: 10.24874/jsscm.2017.11.01.01)

Numerical Study of the Behavior of a Zirconia Dental Prosthesis with Prior Defect

B. Meddour [1*], F. Khadraoui [2], A. Guerraoui [3]

[1] University of Abbas Laghrour, Khenchela 40000 Algeria
e-mail: samsum66@gmail.com
[2] University of Batna2, Batna 05000 Algeria
e-mail: fkhadraoui29081978@gmail.com
[3] University of Batna1, Batna 05000 Algeria
e-mail:gharaouiamel40@yahoo.fr
**corresponding author*

Abstract

The biomechanics field continues with its progress and will not cease to grow due to ongoing research in this area to find better solutions to problems. It is in this context that this work aims to simulate the mechanical behavior of a dental prosthesis made from zirconia. The proposal of zirconia as a material for dental prosthesis is the main aim of this paper. Indeed, Zirconia as a bioceramic material presents many advantages, and especially good biocompatibility and high resistance of wear. On the other hand the disadvantage of this material is its fragility i.e. it has weak strength against cracking. So, in this paper we considered a dental prosthesis assumed to be implanted to an adult person. In order to study the crack initiation we considered a defect in this prosthesis. Using the conditions of blocking and loading by Abaqus simulating tool, we obtained the results revealing the possibility of using zirconia as a material for dental prosthesis.

Keywords: dental, zirconia, simulation, masticator

1. Introduction

Dental prostheses according to their types can be made of one of the following materials:

- Acrylic resins which are thermoplastic polymers.
- Ceramics, including zirconia, alumina and porcelain, are used in the manufacture of adjoining dental prostheses, crowns and bridges.
- Metals often used for posterior teeth include precious metals (gold, silver, etc.) and non-precious metals (nickel, chromium, cobalt, etc.) (Aiche et al. 1984, LeJoyeux 1978)

The zirconia is known by a set of properties making it a candidate material to be used in the biological human environment. Some of the important properties are cited as the following:

- Compressive strength close to 6000 MPa
- Purity up to 95.6%

- Fine grain of the order of 1.5 µm
- Fine roughness ~ 0.02 µm
- Poor thermal and electrical conductivity
- Appearance of the dental prosthesis very close to that of the natural tooth
- A considerable hardness
- Good biocompatibility with the biological environment
- Good resistance to corrosion
- Some lightness (volume density ~ 6 g / cm3) according to Samir (2002)

Despite these advantages, like most ceramics, zirconia has the disadvantage of being fragile i.e. it has weak fracture toughness ($K_{IC}=7MPa.m^{1/2}$).

The advantages cited previously promote the use of this bioceramic material to manufacture dental bridges.

In this context, we considered a dental prosthesis (Fig. 1 and Fig. 2) in zirconia. We created a defect inside it and we performed the simulation passing through the following steps:

- Modelling the prosthesis with a spherical defect
- Inserting the model in Abaqus
- Considering loading and boundary conditions
- Meshing
- Obtaining results

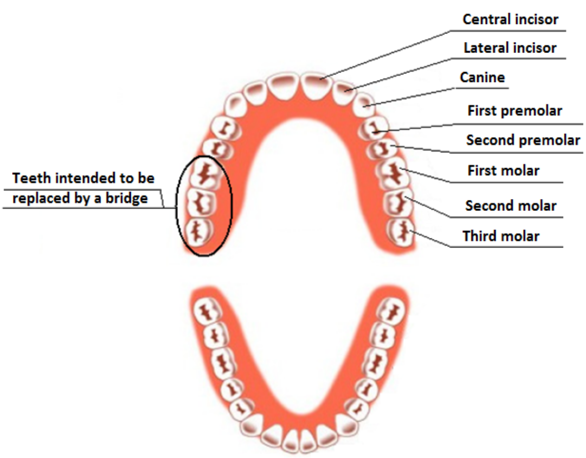

Fig. 1. Types of natural teeth.

Fig. 2. Bridge in zirconia.

2. Materiel & methods

2.1. Boundary conditions and loading

The blocking (Fig. 3) is provided by the support of the bridge on two natural teeth (Fig. 4).

The masticator teeth apply efforts represented by a tangential component F_y*=150N* and a normal component F_z*=150N*

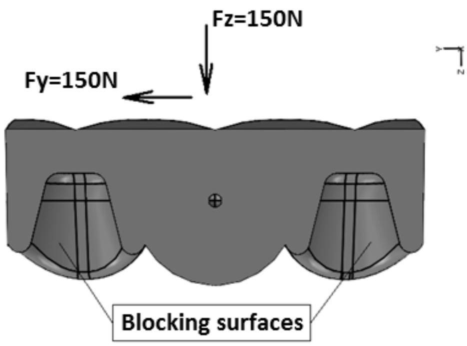

Fig. 3. Boundary conditions and loading according to Smukler (1993)

Fig. 4. Bridge emplacement

2.2. Mechanical characteristics of the bridge material

Material	*Young Modulus (MPa)*	*Coeff of Poisson*	*Fracture Toughness (MPa.m$^{1/2}$)*
Zirconia	*201000*	*0.31*	*7*

Table1. Mechanical characteristics of the bridge material

2.3. Mesh

The selected finite element is the 4 node tetrahedron

	Number of nodes	*Number of elements*
Bridge	*9588*	*46926*

Table2. Meshing data

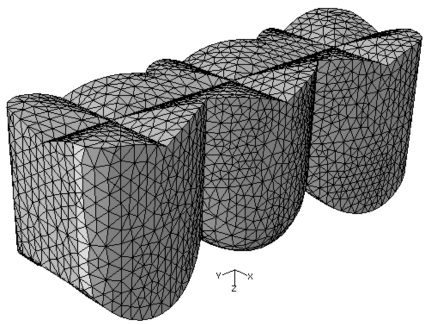

Fig. 5. Bridge mesh

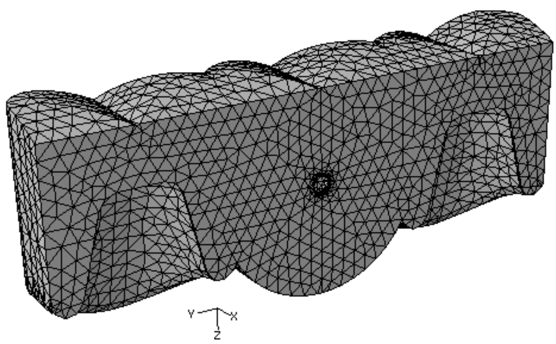

Fig. 6. Detail of the defect (Ø=0.5mm)

3. Results

3.1. Analysis of stresses

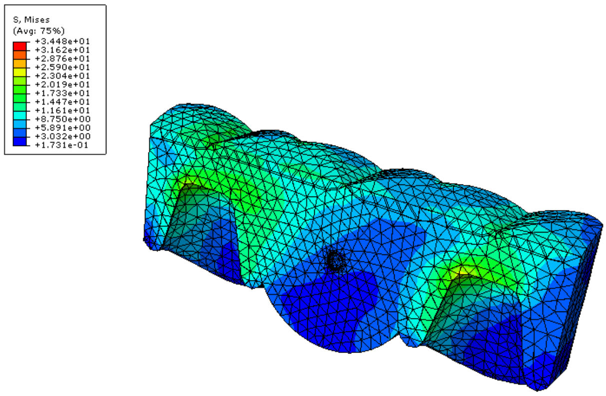

Fig. 7. Distribution of equivalent stresses Von Mises (Longitudinal section)

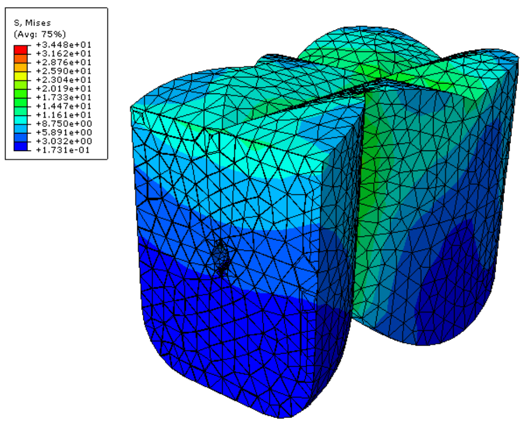

Fig. 8. Distribution of equivalent stresses Von Mises (Cross-section)

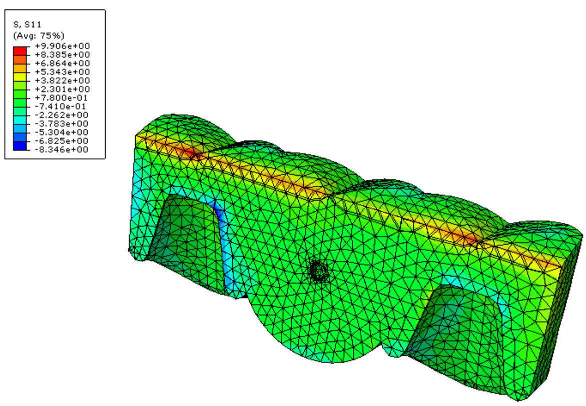

Fig. 9. Distribution of normal stresses σ_{xx} (Longitudinal section)

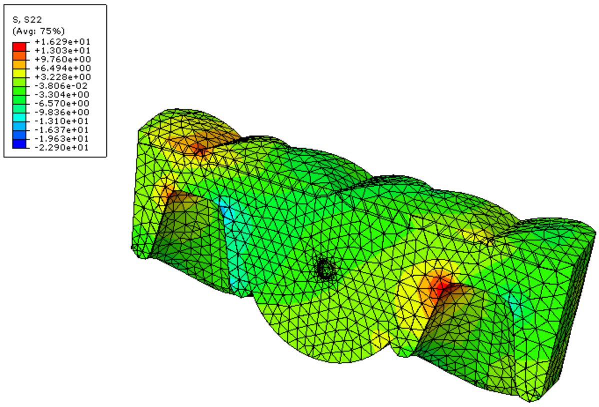

Fig. 10. Distribution of normal stresses σ_{yy} (Longitudinal section)

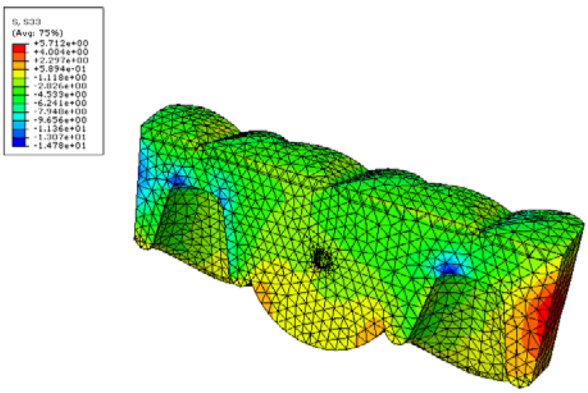

Fig. 11. Distribution of normal stresses σ_{zz} (Longitudinal section)

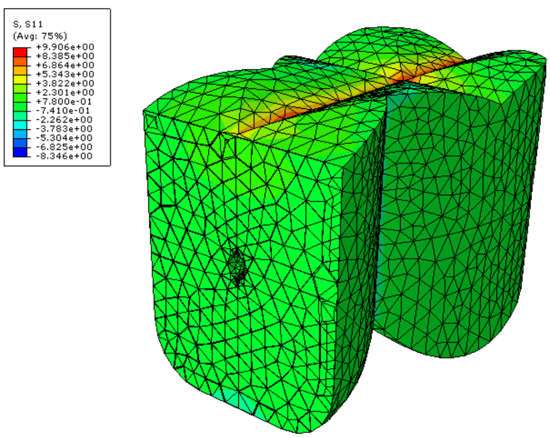

Fig. 12. Distribution of normal stresses σ_{xx} (Cross section)

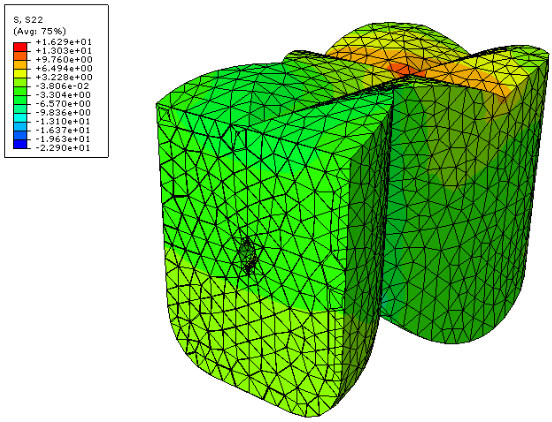

Fig. 13. Distribution of normal stresses σ_{yy} (Cross section)

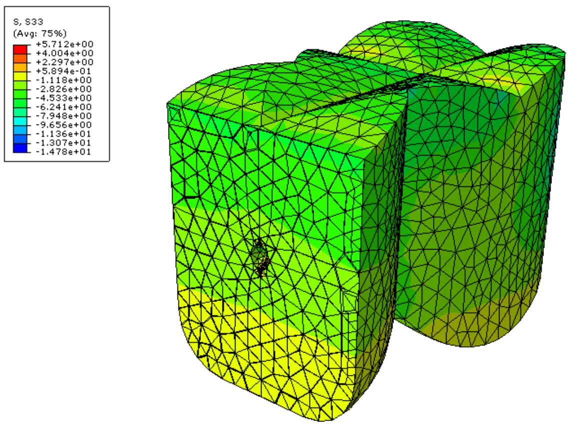

Fig. 14. Distribution of normal stresses σ_{zz} (Cross section)

To see the variations of the stresses in the vicinity of the defect, we considered three directions 1, 2 and 3 that are parallel respectively to the axes y, z and x (Fig. 15). The results are represented on the following plots:

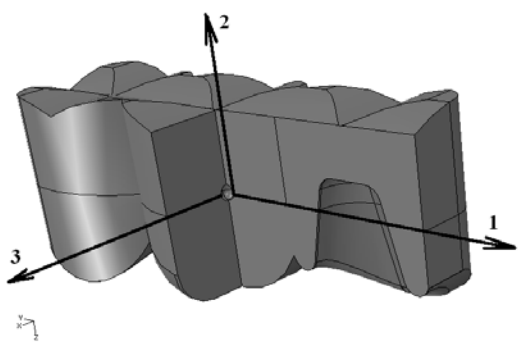

Fig. 15. Axes used in the vicinity of the defect

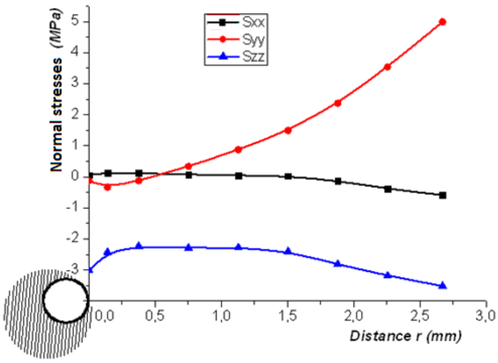

Fig. 16. Analysis of normal stresses on axis 1

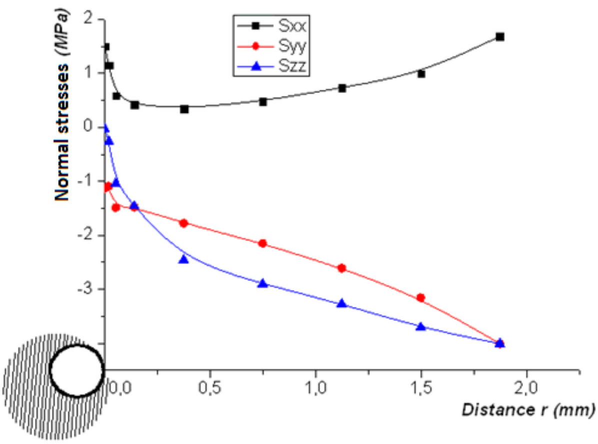

Fig. 17. Analysis of normal stresses on axis 2

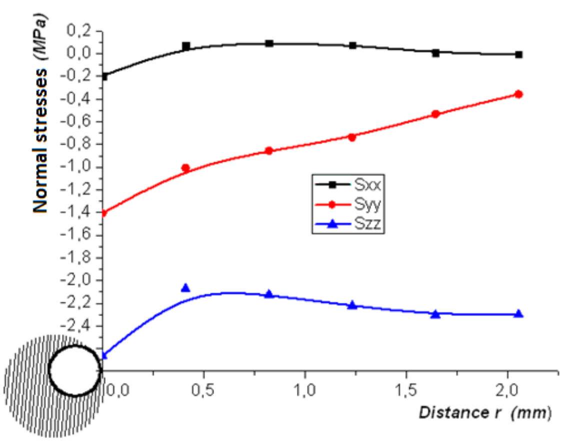

Fig. 18. Analysis of normal stress on axis 3

3.2. Fracture mechanics

The failure can be in one of three modes:

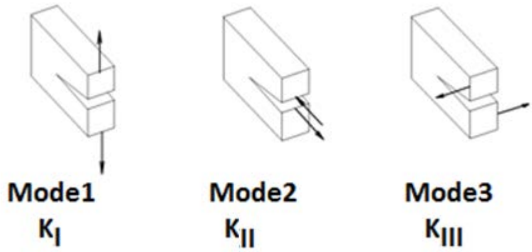

Fig. 19. The three failure modes according to Bernard (1990)

Mode 1 is considered to be the most dangerous; therefore to check the stability of the defect, we simply calculated the stress intensity factor K_I.

The relationships between stresses and stress intensity factor are given by the following relationships according to Westergaard (1939):

$$\lim_{r \to 0} \sigma_{ij}^{(I)} = \frac{K_I}{\sqrt{2\pi r}} f_{ij}^{(I)}(\theta) \tag{1}$$

To determine K_I, the extrapolation method was used on the median plane of the prosthesis and considering the following relation:

$$\sigma_{xx} = \frac{K_I}{\sqrt{2\pi r}} \tag{2}$$

Considering the 3 propagation lines of the crack (Fig. 15), the function K_I (r) is interpolated on th**e** lines 1, 2 and 3:

$$K_I(r) = \sum_{k=0}^{n} \frac{K_I{}^k(r_0)}{k!}(r - r_0)^k \tag{3}$$

The exponent k is equal to the number of used points for interpolation for each direction (Table 3)

Interpolation direction	*Number of point for interpolation*
1	*8*
2	*8*
3	*5*

Table3. Number of points for interpolation

Finally, we extrapolate to the point r = 0.

The following results are obtained:

Interpolation direction	*Normal stresses (MPa)*	*Stress intensity factor K_I (MPa.m$^{1/2}$)*
1	σ_{xx}	*0.924*
	σ_{yy}	*0.074*
2	σ_{xx}	*0.949*
3	σ_{xx}	*0.058*

Table 4. Obtained values of K_I

4. Discussion

The stress distribution patterns (Figs. 7-13) show that there is no stress concentration in the vicinity of the defect, but concentrations are noticed in the other zones where the geometry changes abruptly.

In addition, relatively high values of stresses Von Mises of ~ 34 MPa are noted.

High values are remarkable for normal stresses σ_{zz} ~ 16.23 MPa.

The plots (Fig. 16, Fig. 17 and Fig. 18) show the non-existence of stress concentration in the vicinity of the defect and unaccented variations of normal stresses. For the vertical axis a little singularity is observed. For the other axis, there is no singularity. The non-existence of singularity in the vicinity of the defect is due to the geometry of the prosthesis and boundary conditions and loading.

The values obtained from K_I (the other stresses are not taken into account because they are compressive) are much lower than $K_{IC} = 7MPa\ m^{1/2}$ of the zirconia.

6. Conclusion

In this paper we studied a dental prosthesis relying on two worn teeth. Zirconia was proposed as a material of the dental prosthesis. To simulate the zirconia behavior in terms of strength against cracking, we created a defect inside the prosthesis. After configuring the conditions of blocking and loading and meshing we investigated in different section plans and direction, we obtained results which show that there is neither singularity nor remarkable stresses concentration in the vicinity of the defect and the calculation of the intensity stress factor revealed no intensity of stresses in the vicinity of the defect. Although the study is made of a single viewing angle this paper could confirm the possibility of use of zirconia as a material for dental prosthesis.

References

Aiche H, Antrassian J (1984). Le rôle des dents artificielles en prothèse complète. *QuestOdontostomatol* ,33 ,39-46

Bernard B (1990). Notions pratiques de mécanique générale. *Editions Eyrolles Paris*.

LeJoyeux J (1978). Prothèse complète. 3ème edition, Tome 3. *Paris, Maloineédit.*

Samir H (2002). Etude du comportement en fatigue en compression des biocéramiques (Al_2O_3, ZrO_2) utilisées pour la conception des prothèses ostéo-articulaire. *Thèse de doctorat*.

Smukler H (1993). Equilibration occlusale en denture naturelle. *Paris Edition CdP*, 16-19, 51,81-82

Westergaard H (1939). Bearing pressures and cracks. *Journal of Applied Mechanics*,49-53.