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FINITE ELEMENT ANALYSIS TO PREDICT FAILURE OF BIOACTIVE GLASS USED IN ELECTRON BEAM ABLATION PROCESS

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Abstract. The aim of this study is to investigate the possible causes of the bioactive glass target failure after a few hours and to increase the lifetime of the bioactive glass target in the ablation process. A finite element model was developed, which represent the target and used for simulating the process and following the stress distribution thermally induced by the electron beam. The locally high temperature ~1300^0 C evaporate the material at the surface and after a short time of using, the thermally stress induced produce small cracks in the target body which expand and destroy the target. Also we can observe that the diameter of the spot at the beam-target interaction surface has a great influence in failure of the target. Finally, the failure of the target after a short time is the sum of various causes (high stress, beam power, heat conductivity, high temperature).

Key words: ablation, coating, biocompatibility, bioactive, biomechanics, finite element, heat transfer, Von Mises stress, glass

Finite element analysis to predict failure of the bioactive glass used in ablation process

INTRODUCTION

Bioactive glass (BAG) can be used as a coating material to increase the biocompatibility of implants[1]. A new deposition technique using ablation for producing high quality thin films of dielectric inorganic- and organic compounds and alloys was presented by Müller et al[1]; in this article the application of the technique to BAG is discussed. Directed energy is driven to the target for 60 ns by means of a space charge neutralized, magnetically self pinched electron beam. The maximum electron energy is 15 keV, the total current is 1.5 kA and the current density is up to 10^5 A/cm². The electron beam is generated in a low-pressure gas discharge system, which is simple, reliable and converts electric energy into energy deposited at the target with an efficiency of 30%. The process is comparable to UV laser ablation. Its advantages lie in the enhanced efficiency, the low deviation of $\leq$5% in film stoichiomety, simple handling, no dangerous gases and 20 times lower costs. The process of electron beam ablation with respect to range and heat conduction in the target during deposition is discussed, followed by a review of already deposited materials. Electron Beam Ablation (ELBA) is a deposition technique with high potential for cost-effective deposition of BAG coatings on temperature-sensitive substrates, because the technique does not heat the substrate significantly above room temperature[2]. During the ablation process, the BAG target is rotated with a constant speed and hit under an angle of 45° by a pulsed electron beam with high energy for 100 nanoseconds and with pulse frequencies of 3 Hz. In this very short time, locally the material can be heated up to several thousands degrees C, it is evaporated and it expands in the surrounding atmosphere.

MATERIALS AND METHODS

In the present design, the target is a bioactive glass (BAG) bulk with thickness 7 mm, diameter 30 mm and with a specific parabolic profile. Bioactive glass is modeled as material with isotropic properties. A Gaussian distribution is used for the temporal application of the pulsed electron beam over the target. Only ~4% percent of the total power in the beam heats up the target, but this is enough to evaporate and expand the ablated material in the surrounding atmosphere. A 2 and 3-dimensional model were generated to study the thermal stresses of a single pulse and multiple pulses, respectively. From the beginning we will use triangular elements for the 2D model and linear isoparametric three-dimensional tetrahedron elements for the 3D model. For better results we have to use a finer mesh but we are restricted by the computational time. In this simulation, the target is considered fixed and the applied flux is rotated around the center of the disc with a fixed radius. To simplify the simulation and to reduce the computational time but keeping in mind that results should be sufficiently realistic, an equivalent flux is calculated and an optimal mesh was chosen. For symmetry reasons, only a quarter of the full 3D model with a finer mesh is used to study the effect of a single pulse. Finally, a full

3D model with coarser mesh is employed to simulate the thermal effects of multiple pulses during the simulation of the ablation process.

RESULTS AND DISCUSSION

In the figure 1 we can observe the calculated Von Mises stress distribution in the full 3D model for multiple pulses of the electron beam. The stress increases step by step till it reaches the maximum value (when the point flux is applied in the node) and decreases rapidly but more linear then before the application of the point flux in the node. We observe that the temperature in the body increases with every pulse. The stress expands circularly in the way the flux is applied and on the back side we will see that it creates a tail that becomes sharper in the back side of the area where the flux is applied (looking like a pear or a drop). Figure 2 shows the thermally induced stress in the node where the flux is applied, over a period corresponding to 1.2 target revolutions.

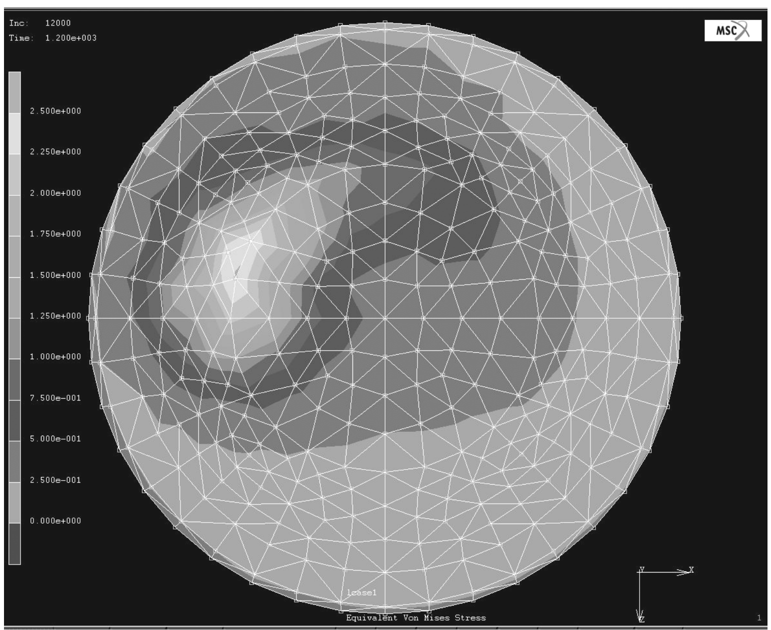

Fig. 1 – Von Mises stress distribution over the target (MPa)

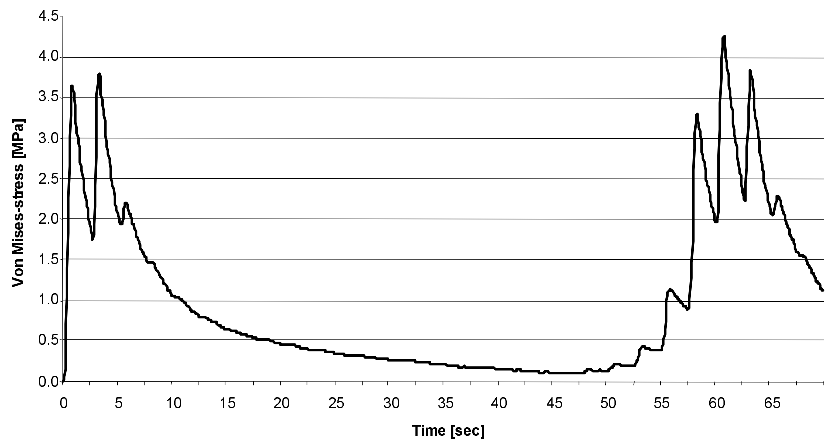

Fig. 2 – Von Mises-stress in the incidence point of the beam as a function of time (70 seconds, 1.2 target revolutions)

Locally the temperature reaches ~1300°C, close to the temperature of vaporization and induces high stresses in material. During ablation, these high stresses produce small cracks in the body and during subsequent cooling and heating cycles the cracks grow until they fracture the target by fatigue loading. The discharge time, the pulse frequencies, speed of rotation and the spot diameter also contribute to premature failure of the target. In the simulation, errors are induced by calculation of equivalent flux, element type, element size and this should be taken into account when interpreting the results. High temperatures are concentrated on the incidence point of the beam because of the low heat conductivity of BAG.

CONCLUSIONS

The bioactive glass is an isotropic material used to coat implants. The ablation process is used in this sense. The model will be used for optimization of the speed of rotation to improve the lifetime of the target. The rotation speed will be optimized to avoid the superposition of the same spot where the beam hits the target in correlation with the beam diameter at the target and the distance from the center point of the target to the application point of the flux. Also including in the model the convection factor we will expect for better results. In order to improve the model a Fortran subroutine will be develop. Future work will include a full 3D analysis to verify the FE results in a more realistic model.

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