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STRESS-STRAIN ANALYSIS OF CERAMIC HEADS IN THE DESTRUCTION DEVICE

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Abstract: *This article deals with the issues of modification of destructive device for ceramic heads of total hip replacement based on the analysis of tensile stress state in the head. The goal of device modification is a shift of the location with extreme value of σ_{1max} from the region of head's hole bottom to its opening. This modification will increase the credibility of the obtained material properties of bioceramics, which will be determined from a set of head destructions using the Weibull weakest link theory.*

Keywords: **Material parameters of bioceramics, Destruction tests, Weibull weakest link theory, Endoprosthesis ceramic heads.**

1. Introduction

Material properties of bioceramic material are determined by standard 3 or 4-points bending tests using the Weibull weakest link theory (Jiang et al., 2011; Basu et al., 2009). This method is useful when samples cut out of the ceramic part guarantee the standardized minimum dimensions. If the sample dimensions are smaller than those given by standards, they show material characteristics of higher values than in reality. This phenomenon is due to the fact that with a decreasing sample volume the probability of a critical length crack decreases; this, under a given stress state, causes a sample fracture.

2. Methods

The above problem will be eliminated if not the sample is destroyed, but a specific element of a brittle material, in our case of bioceramics. It is necessary to expose the entire element to such a load that is close to operational load and generates a tensile stress state in the element. A global objective is to determine the material properties of bioceramics, from which hip replacement heads are manufactured. This hip replacement is attached to the stem taper and loaded on its spherical surface by contact pressure of the cup. This method shows variations and depends on the physiology of the individual patient and on the process of his/her physical activity. Therefore, for the destruction test, we prefer the load used to test the static strength of ceramic heads ISO 7206-5 (Willmann, 1993; Weisse et al., 2003). During this test, the head is pressed on the stem in the direction of the system axis and thus the created character of stress state is suitable for both the assessment of head static strength and also for determination of material properties.

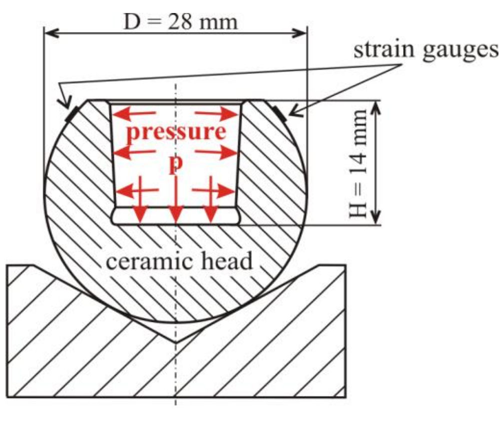

Fig. 1: Head's loading.

In the process of solving the stress state in the ceramic head of total hip replacement loaded according to ISO 7206-5, it was found out that the stress state in the head is heavily dependent on micro and macro shape deviations of tapered contact surfaces (Andrisano et al., 1990; Teoh et al., 2002; Fuis et al., 2001, 2002, 2004 and 2009a). When determining the material properties, it is necessary to carry out destructions of at least 35 samples in which the stress field σ_1.

When destructing the head, it is necessary to know the value

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of tensile strain in order to subsequently determine the stress field. Therefore, two strain gauge transducers (about 1 mm from the edge – Fig. 1) are bonded on the outer surface of the spherical area; these transducers measure circumferential strain of the head under pressure loading (Fuis et al., 2006 and 2010). The entire head is in a special destructive device and the pressure load is exerted by a piston which acts on the rubber disposed in a tapered hole of the head. Rubber acts on the head by internal pressure p; this causes the circumferential tensile strain in the head to destroy it subsequently.

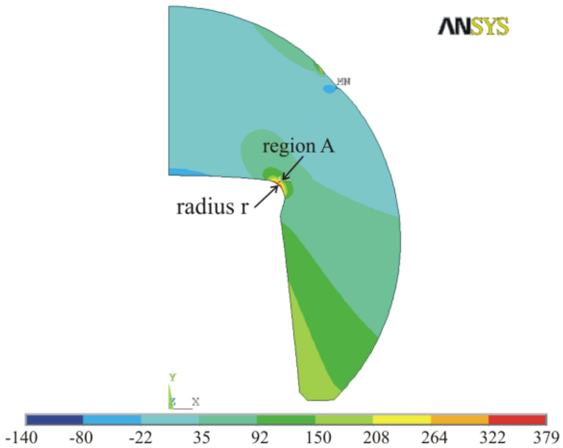

Fig. 2: First principal stress in the head under the pressure loading in MPa.

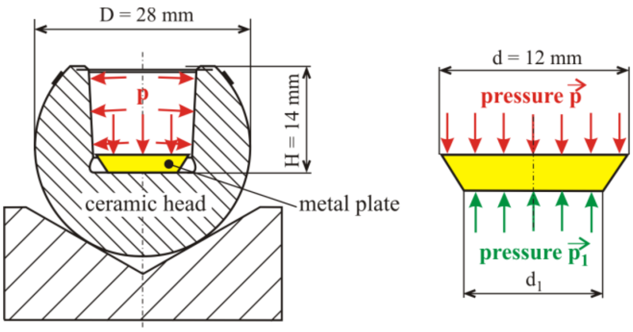

Fig. 3: Treatment of the head's loading in the destruction device..

Isosurfaces of the first principal stress σ_1 in the head under a given pressure load are described in Fig. 2 (Fuis et al., 2004, 2011). This figure shows that the maximum value of σ_1 (379 MPa) is at the transition region of the tapered hole into its bottom (region A) and is dependent on the radius of this transition *r*. After the destruction of each head, it is possible to measure the specific value of the radius and to determine the stress field for specifically measured radius. However, for destruction of 40 heads, this method is time-consuming and computational methodology of material characteristics specified in (Bush, 1993; McLean et al, 1991) is also more complicated. Therefore, efforts have been made to eliminate the stress concentration at the transition region of the taper into the bottom.

One of the options how to eliminate the stress concentration is to prevent the pressure acting in the transition region of the taper into the bottom and also into the part of the bottom of head hole. A metal plate (pad) with a trapezoidal cross-section is inserted into the region of the head bottom, as shown in Fig. 3 (thickness t = 2 mm). The pressure of rubber acts on a pad with a diameter d = 12 mm. This pad is in contact with the head bottom only on the diameter d_1, which can vary. The aim of the analysis is to determine for which diameter d_1 the maximum value of σ_1 in the head will move out of stress concentrator (the opening of the tapered hole).

Computational modelling is performed using the finite element method - ANSYS. Due to the axis symmetry of the analyzed body, the head is discretized by axis symmetric elements. A bond on the spherical surface is modelled as rigid and pressure load is applied to the inner hole of the head - pressure p = 100 MPa acts on the whole tapered part (including the hole termination); pressure p_1 acts in the contact region with the pad – Fig. 3. The value of pressure p_1 is determined from the force balance of trapezoidal pad in the axial direction.

In terms of head geometry it is a variant with an outer diameter of 28 mm, taper of 12/14mm and hole depth of 14 mm (Fig. 1). This type of head has been destroyed by a special destructive device described in greater detail in (Fuis et al., 2006). The head is made of bioceramics Al_2O_3 characterised by the value of modulus of elasticity E = 3.9 GPa and Poisson's ratio μ=0.23 (Fuis et al., 2009 and 2011a).

3. Results and Discussions

Isosurfaces of the first principal stress in the head for pad different diameter d_1 are shown in Fig. 4. With a decreasing size of diameter d_1, the maximum stress is still located in the region A (Figs. 1 and 4) and it almost always obtains extreme values of about 280 – 290 MPa. However, this value is lower than in the

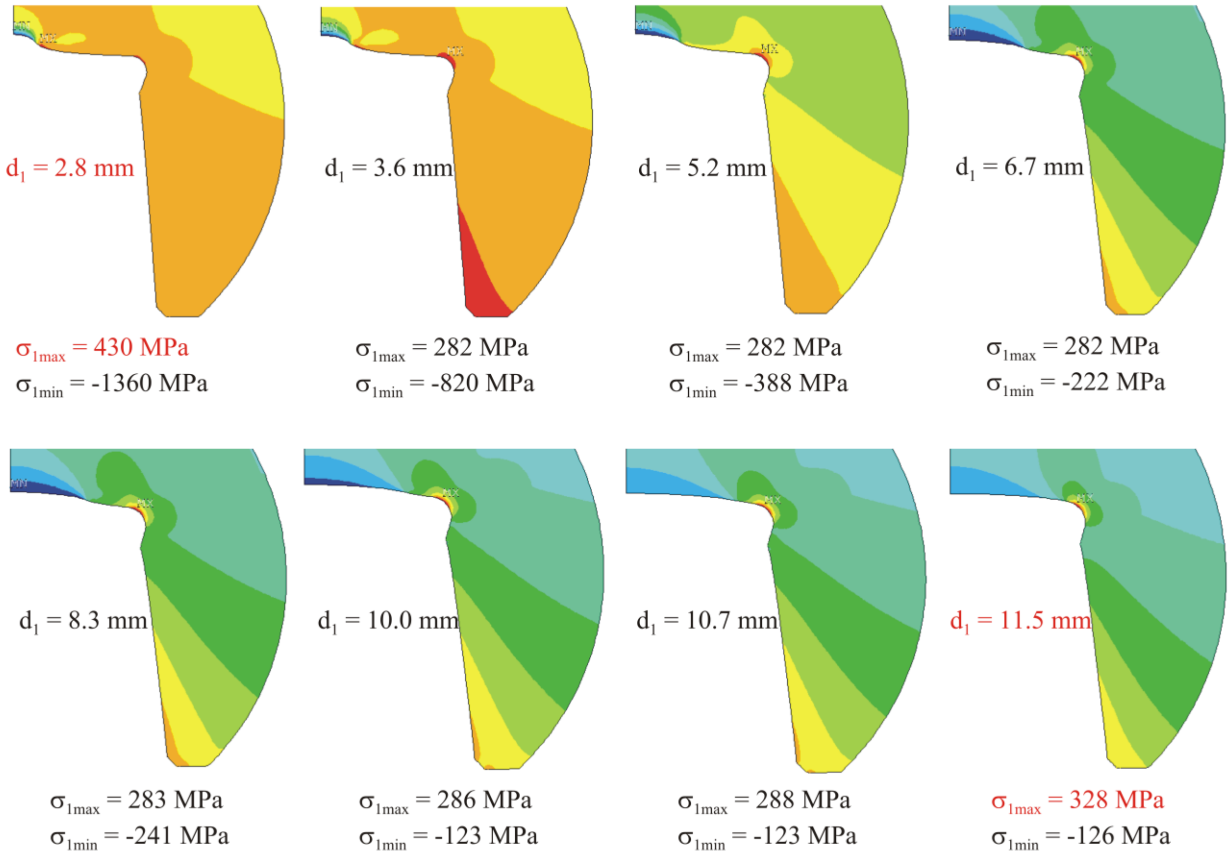

Fig. 4: Isosurfaces of stress σ_1 for different values of the pad diameter d_1 (d = 6 mm, p = 100 MPa).

case of loading of the entire hole by pressure p = 100 MPa (Fig. 4). With a decreasing size of diameter d_1, the pressure p_1 acting between the pad and the head bottom increases. Moreover, with a decreasing size of diameter d_1, the values of tensile stress also increase in the lower portion of the head (in the region of the largest diameter of tapered hole). An exception is the case when d_1 is in the interval between 12.5 and 11.5 mm - in this case the maximum stress is higher than the above 280 MPa due to the fact that the pressure p_1 acts in the vicinity of the stress concentrator, thereby increasing the stress state. If we reduce the size of diameter d_1 up to 2.25 mm, a change in the nature of stress state occurs in the region of the head bottom and the maximum stress is shifted to the region where load pressure p_1 has ceased (maximum value is significantly higher than in the previous cases and it is about 430 MPa). The analysis shows that in this case it is not possible to achieve the elimination of effects of stress concentration in the transition region of the taper into the head bottom.

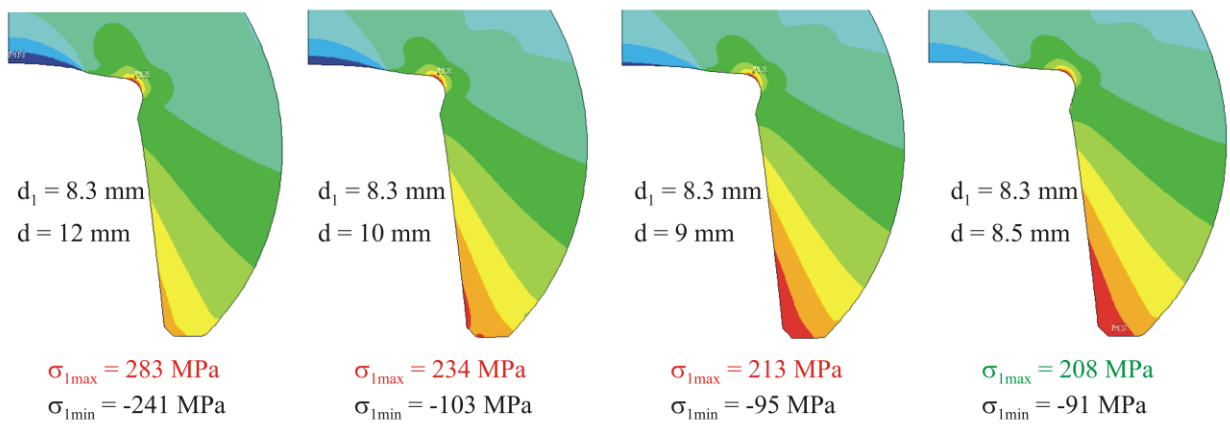

Fig. 5: Isosurfaces of stress σ_1 for different values of the pad diameter d (d_1 = 8.3 mm, p = 100 MPa).

Now there is a possibility to determine for a given diameter d_1 the value of diameter d so that the maximum stress is shifted from the transition region of the taper into the head bottom. The size of diameter d_1 was selected 8.3 mm and Fig. 5 shows the isosurfaces of σ_1 for different pad diameter d_1 (12;

10; 9 and 8.5) mm with corresponding pressure p_1. The results of computational modelling suggest that for the pad having a diameter $d_1 = 8.3$ mm and the diameters $d < 9.8$ mm, the position of maximum stress has shifted from the hole bottom region (region A) to its opening, as shown in Fig. 5 completely right.

4. Conclusions

The aim of this study was to change the way of destroying the heads so that the position of extreme values of tensile stresses has moved from the region of the head bottom to its opening. To achieve this goal it is necessary to insert a trapezoidal pad into the head, which will change the pressure acting in the region of head bottom.

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