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Calculation of the Ceramic Material Parameters from the Destructions of the Hip Joint Endoprostheses Heads

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Abstract – The paper deals with calculation of the parameters of ceramic material from a set of destruction tests of ceramic heads of total hip joint endoprostheses. The standard way of calculation of the material parameters consists in carrying out a set of 3 or 4 point bending tests of specimens cut out from parts of the ceramic material to be analysed. In case of ceramic heads, it is not possible to cut out specimens of required dimensions because the heads are too small (if the cut out specimens were smaller than the normalised ones, the material parameters derived from them would exhibit higher strength values than those which the given ceramic material really has). On that score, a special testing jig was made, in which 40 heads were destructed. From the measured values of circumferential strains of the head's external spherical surface under destruction, the state of stress in the head under destruction was established using the final elements method (FEM). From the values obtained the sought for parameters of the ceramic material were calculated using Weibull's weakest-link theory.

A problem that is being solved is the destruction of the Al_2O_3 ceramic heads of total hip joint endoprostheses *in vivo*, that had occurred, since the mid nineties, in a series of Czech hospitals. The reliability of the ceramic component is based on Weibull weakest-link theory [1] and the failure probability depends on three Weibull's parameters (m, σ_u and σ_o). These parameters are obtained from the statistical analysis of the set of the destructed heads of the hip joint endoprostesis (due to the fact that the heads are too small to cut out the specimens of required dimensions for 3 or 4 points bending). For carrying out the destruction of a set of ceramic heads a special testing jig has been made in which the heads are subjected to compressive load that acts only on the surface of the head's opening (Fig. 1). In the course of the test, circumferential strains are measured on the head's external surface – the destruction strains are the result of each head's destruction. From the strains established under the heads' destruction, the stress field produced by the destruction had to be defined by the computational modelling (FEM). Thus we obtain a set of values of destruction stresses (the first principal stresses) that have to be arranged in descending order. Each *j*-th destructed head is assigned the probability of its failure from the relation $P_f(j) = j/(r+1)$, where j is the serial number of the arranged head and r is the total number of destructed heads, in our case $r = 40$.

The first of Weibull parameters is stress σ_u, which must be lower than the minimum value of the destructed stress of any head. Conservative approach considers σ_u = 0 MPa, then all tensile stresses influence the body's destruction (thus Weibull 3-parameter analysis changes to a 2-parameter analysis). If we do not choose the conservative approach, we can suppose that σ_u = 150 MPa. The second parameter (Weibull modulus m) is connected with the dispersion of experimentally established values and is determined as gradient of a line interlaid with experimentally established data (Fig. 2). The last of the parameters (normalised volume strength σ_0) is calculated for failure probability P_f = 1-1/e. The calculated material parameters are the following: 2-parameters (conservative approach) - $\sigma_u = 0$ MPa, $m = 5.3058$ and $\sigma_0 = 583$; 3-parameters (non-conservative approach) - $\sigma_u = 150$ MPa, $m = 2.6222$ and $\sigma_0 = 318$.

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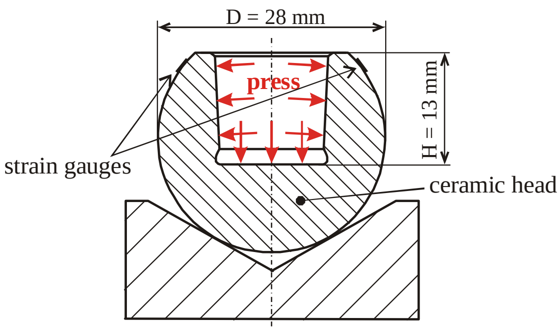

Figure 1: Loading of the ceramic head in the testing jig.

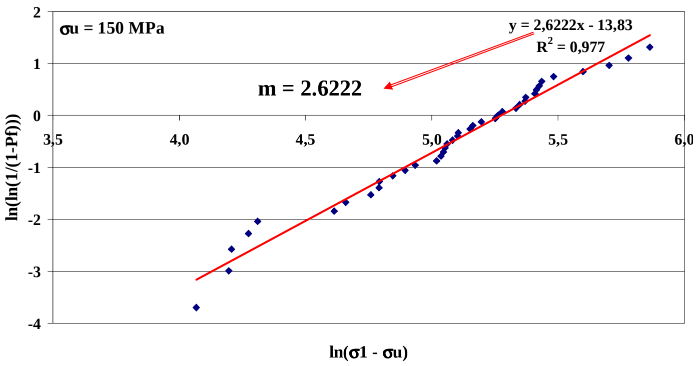

Figure 2: Weibull plot of the normalized modulus of rupture data for 3-parameters Weibull analysis σ_u = 150 MPa.

[1] Bush, D.: Designing Ceramic Components for Structural Applications. J. Mater. Eng. Perf. ASM Int., 2, pp. 851-862, 1993.