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Strain state and strength of acetabular component of total hip-joint endoprosthesis

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The paper deals with the new cementless acetabular cup of the Beznoska type. This cup is made of 1 mm thick titanium covering and polyethylene inner layer. Good initial implant stability is ensured by titanium projections on the outer surface. The purpose of the experimental research was to measure strains at selected points on the outer surface of the artificial cup. A computation model enables us to analyse the strain state generated not only by concentrated load, but also by uniformly distributed load or by varying load. The aim of the research was to analyze the strain state of the acetabular component and to find out the limit loading for assessment of strength and the loss of stability of the cup structure.

Keywords: experimental and computational modelling, strain gauge measuring, stain state, strength, acetabular component

1. Introduction

Many surgeons and bioengineers have contributed to the concepts, techniques, and designs of prosthesis for total hip replacement, but one pioneer in particular stands out. Sir John Charnley reported in 1961 his clinical experiences with a steel femoral component and a plastic acetabular cup. Charnley revolutionised the field with invention of self-curing acrylic cement used to fix the prosthetic components into the bone. These advances greatly improved the success rate of total hip replacement (THR).

Many different designs of THR components are now available. Because hip prostheses must function under high cyclic loads for many years, material strength is critical in preventing excess wear and fatigue fractures. Acrylic cement successfully maintains fixation in the older patients. However, in young, active, or very heavy patients, implants do loosen with time. Cementless implants were developed for these high-risk groups. These implants are stabilised by material design and bone ingrowth. Good initial implant stability is needed to maximize ingrowth. Although technically the application of the hip-joint endoprosthesis has been highly successful, there still remain a number of problems caused e.g. by the interaction between elastic bone tissue and the rigid stem of the replacement.

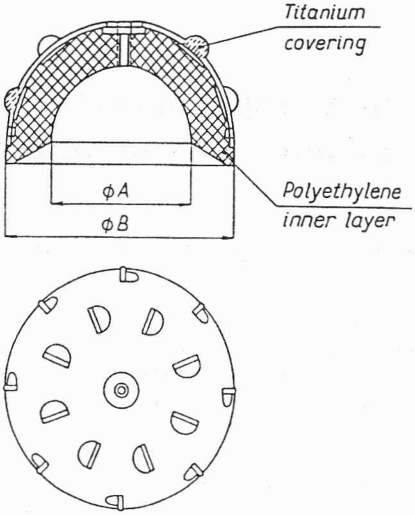

Fig. 1. Scheme of a new type of acetabular cup

The paper deals with the analysis of the strain state of the cementless acetabular cup of the Beznoska type (Fig. 1). This cup is made of 1 mm thick titanium covering and polyethylene inner layer. Good initial implant stability is ensured by titanium projections on the outer surface. The aim of the research was to gain a basic knowledge about a forced flow through the composed structure. An experimental analysis of strain measurement on the outer titanium surface was carried out and a finite-element model was constructed.

2. Experimental analysis of behaviour of acetabular cup

The purpose of the experimental research was to measure strains at selected points on the outer surface of the artificial acetabular cup. The experiment proceeded under the boundary conditions of externally statically determinate system subjected quasistatic loading. The lower part of the loading system was formed by two circular steel plates with a ball sliding between them. The cup base could move along a horizontal plane, which represented hinged support. The loading force was transmitted to the upper part of the cup through a ball that could rotate freely in two hollows (Fig. 2). In the experiment, the method of strain gauge measuring was used. Four strain gauges, EA-05-062TT-120 type, were stuck on the titanium surface on two levels, 5 mm under the applied force and 10 mm above the support (Fig. 3), i.e., strain values were measured in two directions, perpendicular and parallel to the horizontal plane.

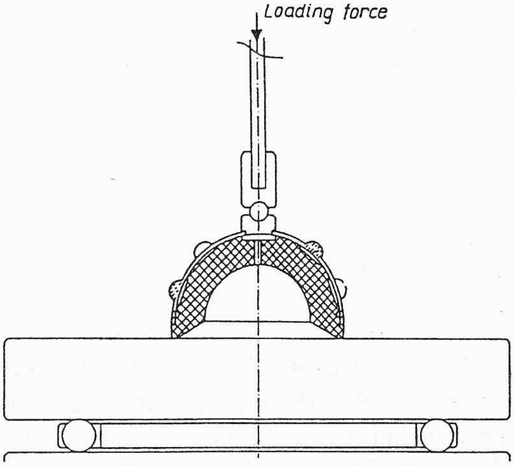

Fig. 2. Testing system

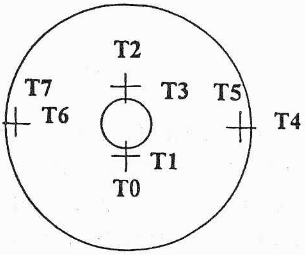

Fig. 3. Plot of cup with scheme of strain gauges

The aim of our experiments was to follow the deformation process up to ultimate load. The loading force was produced by an Instron 4301 electronic tester in several steps:

- up to 1000 N: no plastic deformation occurred;
- up to 3000 N: plastic deformation occurred and during a next loading we observed hardening of the material;
- up to 3500 N: the strain gauges stuck close to applied loading were destroyed.

The force was transmitted through the ring with the thickness of 1 mm at the top of the cup. This means that we are on the safe-side as the loading is applied in the place of a significant weakening of the spherical titanium shell.

3. Computational modelling of strain state of acetabular cup

Using a computation model we can analyse the strain state generated not only by concentrated load, but also by uniformly distributed load or by varying load, which would be very difficult to apply during experimental measuring. We can also analyse strain state not only on the surface, but also in an arbitrary region. The mathematical model links up with the results of experimental research. On the base of experimental results we can verify the correctness of the mathematical model and further use it for the analysis of the strain state in an arbitrary place. The calculation was made using the finite element method by applying the ANSYS programme, version 5.4.

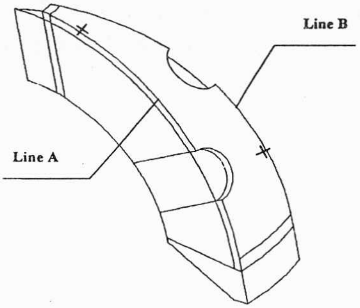

Fig. 4. Computation model of a one sixteenth of cup

The geometrical shape of the hybrid cup construction is described by 6.547 elements of three types and 10.308 nodes. For the reason of symmetry the three-dimensional model is designed as a one sixteenth of the whole cup. Both components, thin titanium covering with holes and polyethylene inner layer, are modelled by 20-node three-dimensional isoparametric elements SOLID95. The individual SOLID95 elements suited well to a model curved surface and make possible linear and non-linear material solution. The translation of the loading on top of the cup into the volumetric elements is realized through surface elements SURF22. The covering and inner layers are modelled separately and their co-operation is provided by equal displacement in the direction of the normal to the spherical surface. The x-axis proceeds in radial direction, the y-axis in peripheral direction, and the z-axis in the direction of spherical axis. Boundary conditions on the side of the model make use of the model symmetry and the polyethylene layer is simply supported at the bottom, i.e. the loading is transferred only in the direction of the vertical hemisphere axis. The loading was realized in accordance with experiments, i.e. uniform loading at the ring with the thickness of 1 mm.

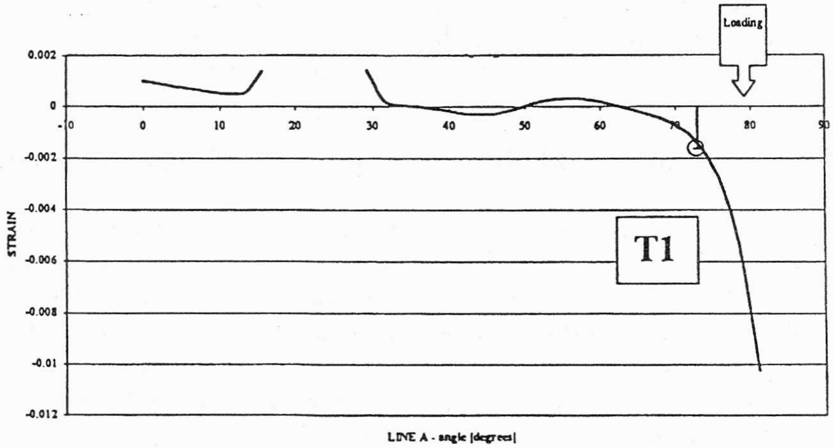

Fig.5. Course of the parallel strain εy along line *A*

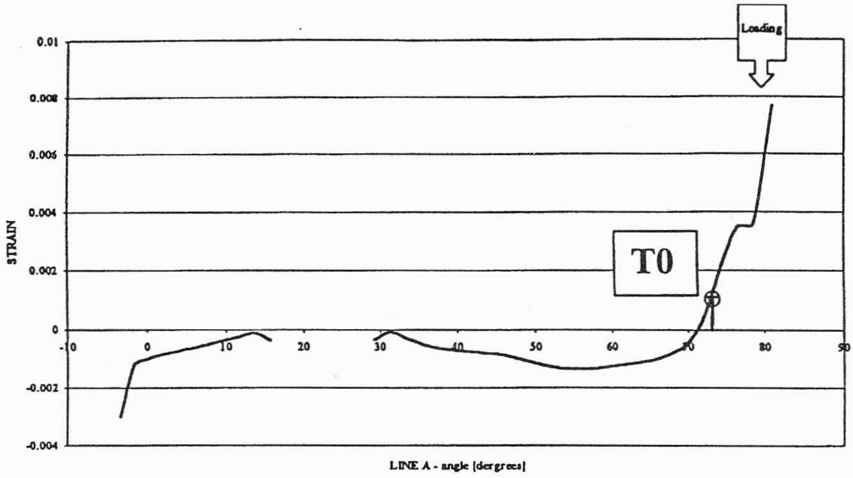

Fig. 6. Course of the meridian strain εz along line *A*

4. Conclusions

The consistency of experimental and numerical results is very good (see Figs. 5, 6). One of the purposes of the experimental research was to find out the limit loading where the loss of stability appears on the top of the cup. During the whole loading cycle up to 5.000 N we did not watch any point on the cup surface with the loss of stability. We can state that the titanium covering is sufficiently rigid to prevent snap-through.

The experimental results showed that the yield point was reached at 1.700 N during the first loading cycle and the second cycle up to 3.000 N showed a certain hardening of material. The strain values reached during the experimental analysis were below the ultimate strength of the material. We used the system of loading in the form of concentrated load, which is on the safe-side in comparison with actual loading of the cup fixed in acetabulum where the loading is continuously distributed.

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References

[1] RUBRICIUS D., JÍROVÁ J., ŠÍDA V., *Strength of System: Acetabular Ceramic Cup with Polyethylene Layer, Ceramic Head and Prosthesis Stem*, [in:] Proc. of 8th Meeting of ESB, Rome, Italy, 1992.

[2] BERNAKIEWICZ M., BĘDZIŃSKI R., *Stress Analysis in the Human Femur with Different Types of Stems of the Total Hip Endoprosthesis*, Proc. of 9th Intern. Conf. on Mechanics in Medicine and Biology, Ljubljana, 1996, pp. 543–547.

[3] JÍRA J., JÍROVÁ J., MICKA M., *Experimental stress analysis of hip-joint endoprosthesis made of carbon composite*, Proc. of Fourth International Conference on Composites Engineering, Big Island of Hawaii, July 6–12, 1997, pp. 493–494.