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EXPERIMENTS PROPOSED WHEN DEVELOPING CAGES BASED ON A CARBON-CARBON COMPOSITE

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Abstract: *A project developing intervertebral implants based on a carbon-carbon composite was initiated by some extraordinary characteristics of this material. The C/C-composite shows very good bio-tolerance, has a lower modulus of elasticity than titanium and its alloys, is X-ray transparent, and stimulates both tissue and bone to grow well into them. The samples used in this study have been C/C-composites based on a plain-woven cloth and UMAFORM LE phenolic resin as a matrix precursor. Experiments to assess mechanical characteristics of the C/C-composite have been proposed by applying the MTS Minibionix testing machine, the biomedical extensometer MTS 634.31F-24 and strain gauges made by the Hottinger and Vishay firms. A FEM contact model has been developed, consisting of lumbar vertebrae* L_3 *and* L_4*, a pair of implants of the PLIF type, and a pair of internal fixations. This model aims at assessing the stresses not only in the implants themselves but also in the adjacent vertebrae. The problem has been analyzed with the use of ABAQUS software, version 5.8-15. The structure of the vertebrae was modeled from C3D8 8-node linear brick elements.*

Keywords: carbon – carbon composite, intervertebral cages

1. Introduction

Osteosynthesis of the lumbar spine is currently treated by implants of anterior and posterior types. A project developing intervertebral implants based on a carbon-carbon composite was initiated by some extraordinary characteristics of this material. The C/C-composite shows very good bio-tolerance, has a lower modulus of elasticity than titanium and its alloys, is X-ray transparent, and stimulates both tissue and bone to grow well into them. A disadvantage of the C/C-composite, i.e., a loosening of carbon particles into the neighboring tissue, can be eliminated by impregnating and covering the C/C-composite by a compatible material (poly[2-hydroxyethyl methacrylate]). The project aims at applying the C/C-composite with a titanium mantle and without the mantle, to create T+C/C-, and C/C-cages, respectively.

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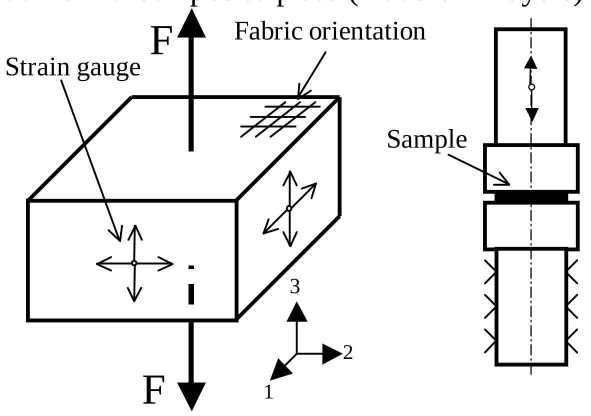
2. Materials and Methods

The samples used in this study were 2-D C/C-composites based on a plain-woven cloth (Torayca carbon fibers, T 800H, Japan) and UMAFORM LE phenolic resin (SYNPO Ltd., Pardubice, CR) as a matrix precursor. The cured samples were carbonized at 50^0C/hr up to 1000^0C in nitrogen. Three-step impregnation with a phenolic resin was used. Subsequently, HTT up to 2200^0C in argon was applied. Pyrolytic carbon was deposited from propane in the tumbling bed reactor, at ambient pressure, at the reaction temperature of 850^0C. Final values of the open porosity and apparent density of the samples were 6 % and 1.6 g/cm^3, respectively. The samples were infiltrated and covered with poly[2-hydroxyethyl methacrylate] in the autoclave under pressure.

3. Experiments

Experiments proposed has been divided to two groups for: i) obtaining characteristics of the C/C-composite; ii) verifying FEM stress assessment of Ti-cage specimens produced by the firm of MEDIN. The MTS Minibionix testing machine has been used in combination with the biomedical extensometer MTS 634.31F-24 and strain gauges made by the Hottinger and Vishay firms.

The measurements of **C/C-composite samples** cut from a composite plate (made of 7 layers) **perpendicularly** to the cloth fibers:

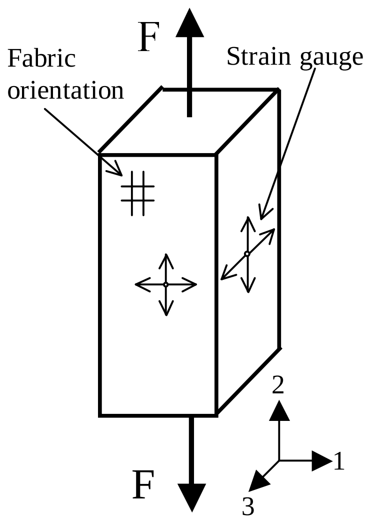


1) 2-D samples of 10x10x2 mm loaded in tension/compression *perpendicularly* to the layers by means of jigs glued to the sample surfaces. The test aim: elastic modulus $E_{3t,c}$, limit strength $\sigma_{3lim;t,c}$ (tension/compression).

2) 2-D samples of 80x10x2 mm loaded in tension/compression *parallel* with the layers. The test aim: elastic moduli $E_{1t/c}$ = ($E_{2t/c}$), limit strength $\sigma_{1(2)lim;t/c}$, Poissoin's ratio μ_{12}.

3) 3-D samples of 80x10x **6** mm loaded in tension/compression:

i) **parallel** with the layers:



a) *strain gauge crosses* applied *parallel* with the fibres. The test aim: elastic moduli $E_{1(2)t/c}$, limit strength $\sigma_{1(2)lim;t/c}$, Poissoin's ratio μ_{12} = μ_{21}.

ii) *strain gauge crosses* applied *perpendicularly* to the fibres. The test aim: Poissoin's ratio $\mu_{13} = \mu_{23}$.

ii) **perpendicularly** to the layers:

strain gauge crosses applied *perpendicularly* to the fibres. The test aim: elastic moduli $E_{3t/c}$, limit strength $\sigma_{3lim;t/c}$, Poissoin's ratio μ_{31}= μ_{32}.

The experimental verification of stress state of **Ti-cage specimens**:

Ti-cage specimens loaded in physiologic way by means of fixtures. The test aim: stress distribution to verify computational results.

4. FEM Application

Great attention was paid to computer simulations of the stress states in the intervertebral implants and the adjacent vertebrae by means of the finite element method (FEM). In the course of the project a number of computational models were worked on, and these provided valuable information about the stress distribution in implants of various concepts. Gradually, a relatively complicated contact model has been developed, consisting of lumbar vertebrae L_3 and L_4, a pair of implants of the PLIF type, and a pair of internal fixations. This model aims at assessing the stresses not only in the implants themselves but also in the adjacent vertebrae. The problem was analyzed with the use of ABAQUS software, version 5.8-15, The structure of the vertebrae was modeled from C3D8 8-node linear brick elements. The vertebra material was chosen to characterize the bone tissue as well as possible. The thin external layer of the vertebra, made up predominantly of compacta, was treated as isotropic and linearly elastic. On the other hand, the spongy tissue inside the vertebra was modeled as anisotropic, and, besides, its elastic properties change in the direction from the vertebra center to its surface. This relatively complicated definition aims to respect the relation of the elastic modulus of the spongy bone to the trabecular density of the spongiosis. The posterior implants made of C/C-composite considered as orthotropic elastic were composed of C3D8 elements whose local coordinate systems were oriented to take into account the structure of the TORAYCA fabric. The whole model was stabilized by means of B31 structural beam elements of the BEAM type, which model the internal fixations applied in these types of operations. The internal fixations are screwed to the vertebrae by means of pedicle screws which were also modeled by B31 structural elements, but with a different definition of the cross-sectional characteristics. The material of the internal fixations and the pedicle screws was chosen isotropic and linearly elastic in order to correspond to the Ti6Al4V alloy. The whole FEM model comprises 72408 elements, including the contact elements which serve to define the contact surfaces.

5. Results and Discussion

A microscopic examination showed that the poly[2-hydroxyethyl methacrylate] was present not only on the surface of the composite but also in its pores and cracks. The C/C-composite has been tested: i) *in vitro* (cell proliferation); ii) *in vivo* (by implanting into the femurs of pigs and by subcutaneous implantation into rats).

The computational FE-models of the implants themselves provided a relatively good idea about the stress distribution and the sites of the maximum stress values in the implant. These models have also been used to verify results obtained when applying more complex contact models, which are still under development, due to great difficulties in formulating the boundary conditions. The stress distribution obtained by one of the contact models is shown in Fig.1

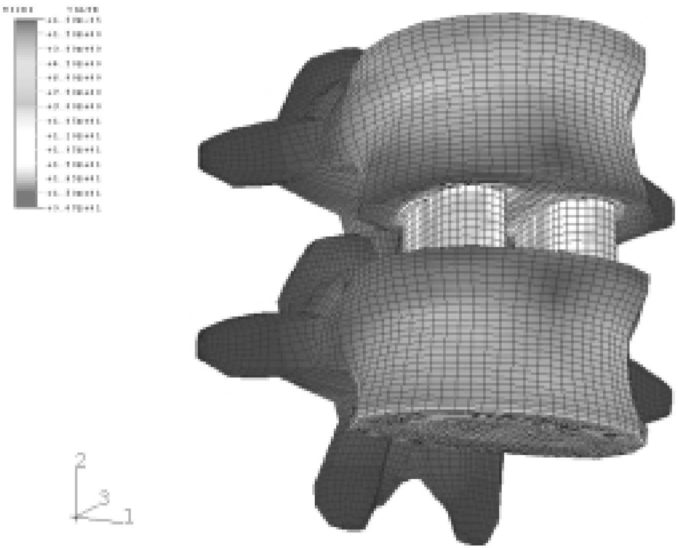


Figure 1: Von Mises stress distribution of a contact model of vertebrae L_3-L_4 with a pair of C/C-composite implants being vertically loaded.

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