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Mechanical characteristics of materials to be used in bone surgery

Mechanické charakteristiky materiálů užívaných v kostní chirurgii

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The paper deals with testing polymers and composite materials useable in orthopaedy in the form of intervertebral cages applied at lumbar spine injuries treatment. A cage made of a PEEK (PolyEtherEtherKetone) material, produced by the firm of DePuy AcroMed™, Johnson & Johnson, and C-C composite material samples produced by using various technologies were tested. Some interesting results obtained from the experiments completed are critically presented in this paper.

Key words: bio-material testing, PEEK intervertebral cage, C-C composite material, spine surgery

Introduction

The paper deals with testing polymers and composite materials useable in orthopaedy in the form of intervertebral cages applied at lumbar spine injuries treatment. One of polymer cages applied in surgical practice is a cage made of a PEEK (PolyEtherEtherKetone) material produced by the firm of DePuy AcroMed™, Johnson & Johnson To obtain an outlook about a load-carrying capacity of this cage, experiments were projected consisting in the cage compressive loading by means of fixations to eliminate a non-parallelism of the cage faces. Some results obtained are presented in this paper. As a further perspective material to be used for spine healing, carbon-carbon composite materials have been also investigated. A complex experimental project has been designed, first results of which being discussed in this paper.

Laboratory equipment

The experiments were carried out using the MTS Mini Bionix testing machine (MTS Systems Corp., USA) linked with the M1000 dynamic exchange containing six measuring channels and the M110 amplifiers 1, measuring range 0,1 – 20mV/V, (Mikrotechna Praha) were used in both experiments. It allowed measuring half or the whole-bridge connection of strain gauges. Its analog output was connected to the input of the MTS control unit, which issued in a synchronized collection of all data.

PEEK cage testing

Materials and methods

PEEK (Polyetheretherketon) is a high temperature resistant engineered thermoplastic with excellent chemical and fatigue resistance plus thermal stability. It exhibits a superior mechanical and electrical properties. PEEK, a unique semi-crystalline, a high temperature engineering thermoplastic, is an excellent material for a wide spectrum of applications where thermal, chemical or mechanical properties are critical to performance. Especially significant, in this regard, is PEEK‘s ability to retain bending and tensile properties at very high temperatures. The addition of glass fiber and carbon fiber reinforcements enhances the mechanical and thermal properties of the basic PEEK material.

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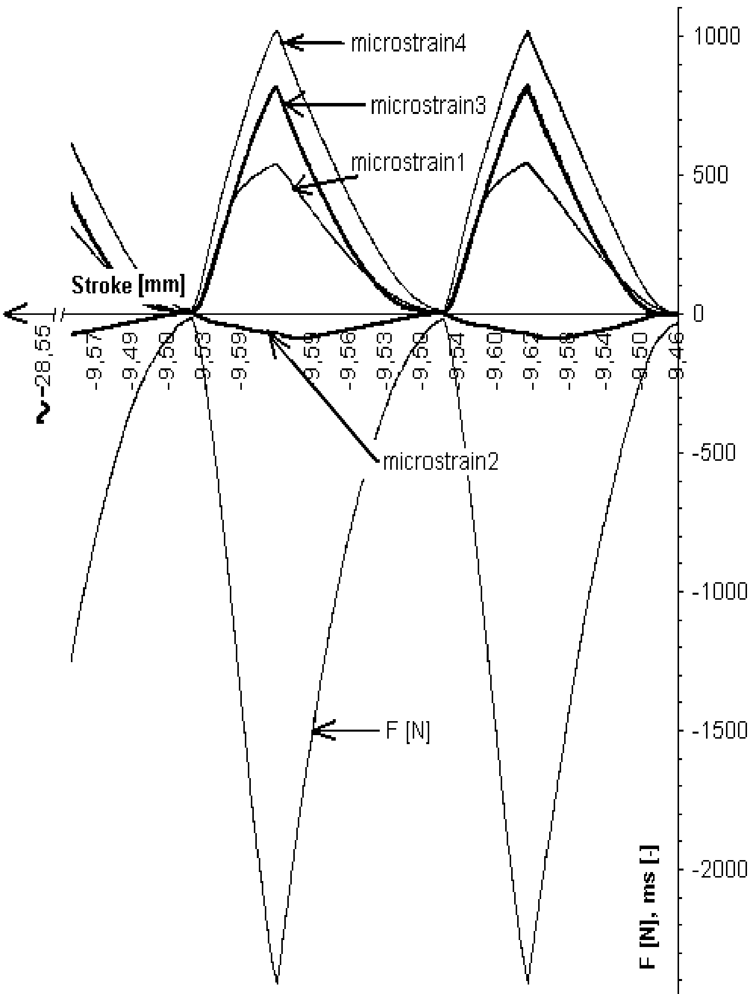


Fig. 3 Loading of intervertebral cage made of PEEK

The paper deals with an experimental analysis of PEEK mechanical characteristics as a biomaterial proposed for applications in orthopedics in the form of intervertebral cages used for the treatment of injuries of the lumbar spine. In comparison with standard measurements, a complication caused the cage non-parallel faces. To ensure a full-contact between specimen and hydraulic jaw of the tested specimen, special fixtures were manufactured. These fixtures became a part of the MTS hydraulic jaws. On the cage side surfaces, strain gauges made by HBM were installed supplied with four thermal stable resistors TESLA TR 162;NC; 120 ± 0,02%. A loading scheme chosen was as follows: a higher-rate pre-loading (repeated 3x) and afterwards a lower-rate loading. During all the four cycles, there was a maximum compressive loading force of 2,4 kN applied. In Fig.3, the force-strain relations are shown for all the strain gauges where notations of *microstrain 1,2* (3/120 XY91-cross and *microstrain 3,4* (two 3/120 LY51) mean: 1- the cage longitudinal direction and 2,3,4 – the cage cross direction (i.e., the loading direction).

Results and discussion

As it is evident from Fig.3, the strain values measured by the strain gauge cross (*microstrain 1,2*) do not match a logic expectation: *strain gauge 1* should show elongation and *strain gauge 2* shortening. The measurement method was changed several times, because of better objectivity. First, repeated measurements were carried out by means of special fixtures, then the fixtures were rotated in the hydraulic jaws about 180° and the measurement was repeated again. Afterwards, some kind of a foam material was inserted between the specimen and the fixtures, to attain a full contact between their surfaces, and a loading force –100N was applied repeatedly. Just to ensure a perfect contact between the fixtures and the intervertebral cage whose both upper and lower faces are sloping and dented to be fixed in intervertebral space, it brought about some difficulties. After a careful examination (by a micrometer) of the respective part of the cage face, a gap between it and the fixture was proved, Fig.4.,

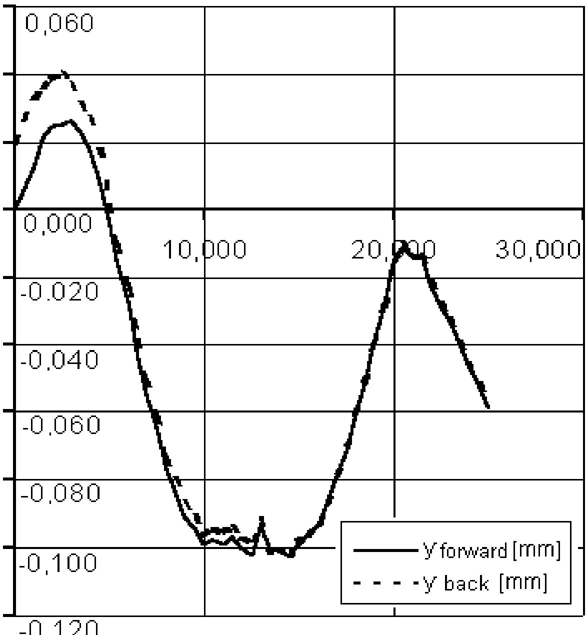


Fig. 4 Quality of specimen's surface

which could not ensure sufficient full-contact between the fixture and the specimen. This problem will be solved by using a cementation of pores and applying higher loading values.

Carbon-carbon composite materials testing

Materials and methods

Carbon-carbon composite samples are prepared as carbon-carbon composites based on plain-woven cloth (Torayca carbon fibres T 800) and carbonized at 1000^0C at the heating rate of 50°C/hr up to 1000°C in nitrogen. The production continues with three-step impregnation with phenolic resin at 2200°C. Our analysis of stress is applied on three different kinds of this composite with different final production technology applied. The surface is covered with pyrolitic carbon and final C-C samples are impregnated with pHEMA (Poly Hydroxy Ethyl Methyl Acrylate) solution in autoclave. Not only a composite material exhibiting high strength values has been looking-for. Based on a complex analysis, a C-C composite exhibiting a compromise between a relatively sufficient strength value, a relatively low modulus of elasticity, comparable with that of human bone, and also between sufficient porosity, which would be favourable for tissue and bone ingrowth, has been developed. The first research part deals with testing of C/C-composite samples prepared as small specimens [see Fig.1, specimen **1**)]. The testing machine jaw displacement (stroke) [mm], load [N], angle[deg] and torque[Nm] were measured in a configuration when the loading force was perpendicular to the composite laminae. It wasn‘t possible to use strain gauges, due to the small dimensions of this specimen and the mode of load application. Specimen to be measured were prepared in the following modes: i) carbonized; ii) carbonized + 1x impregnated; iii) carbonized + 3x impregnated. Basic problem appeared to determine a maximum load. After evaluating a first attempt of 24kN, the maximum force applied was reduced to 18kN for only carbonized samples. When testing further specimen modes, the maximum forces applied were modified with effort to prevent the composite samples matrix destruction. After obtaining the load - displacement graphs, resulting stresses and strains were computed while applying specimens dimensions and corresponding stress-strain graphs were drawn (see Fig.2). Based on the linear part of the stress-strain graphs, corresponding moduli of elasticity E_3 in compression for the tested material types were assessed. A cardinal problem has been to define a limit stress σ_{3lim} in compression for each material mode. Being limited with number of samples prepared (to be sufficient for a statistic informative value), an examination of the matrix state at various load levels (by a polished surface microscope scanning) was not possible. When studying the stress-strain curves two knees can be observed (curve 1 is a typical one): the first knee at a very small load was attributed to an interface contact creation between the sample and the jaw; the second knee seemed to inform us about a yield starting in the matrix and thus naturally being a limit stress value. Another tests planned and carried out have been based on different dimensions of measured specimens. Their dimensions allow us to use strain gauges while applying loading forces both in parallel direction, Fig.1, specimen **2)**, and in perpendicular direction, Fig.1, specimen **3)**, to the composite laminae.

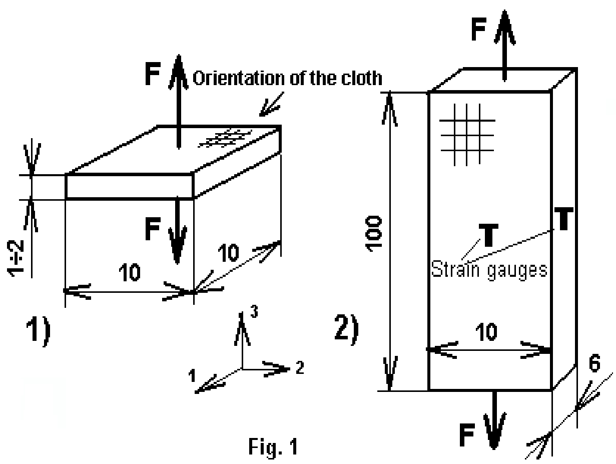
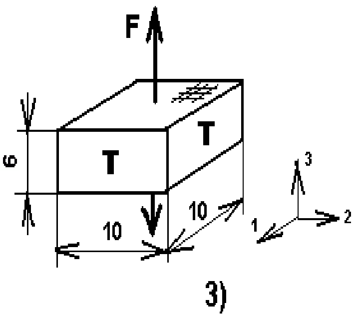
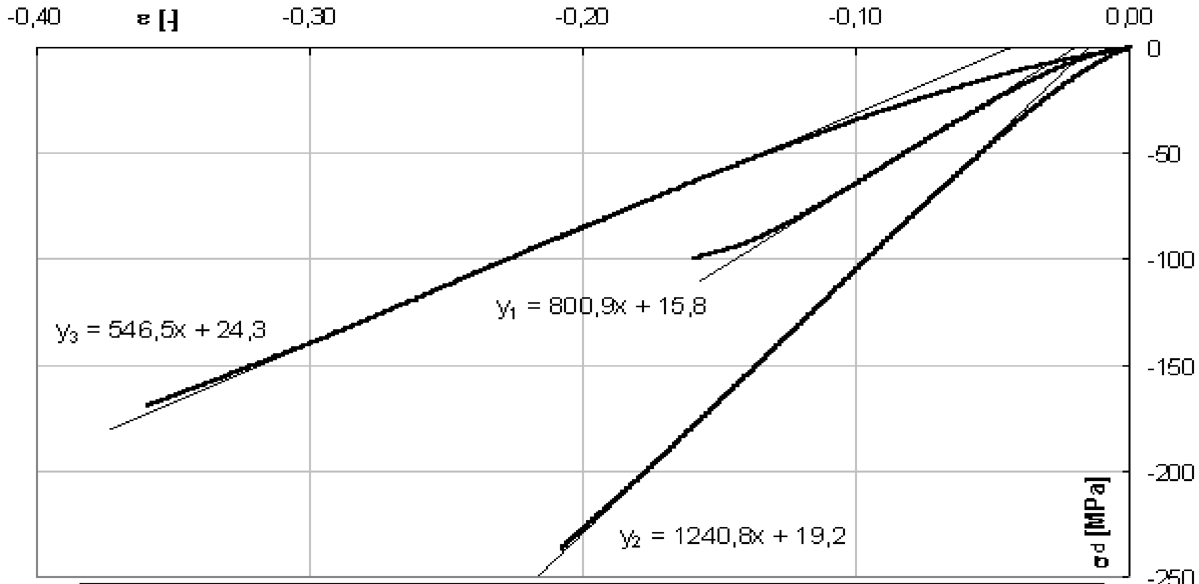


Fig. 1

According to the tests planed, more complex information about carbon-carbon composite are to be obtained: Specimen **2**): E1 and E2, respectively, $\mu_p = \mu_{12} = \mu_{21}$; μ_{pt} and $\mu_{13} = \mu_{23}$,respectively and stress limit values $\sigma_{1,2lim}$ both in tension and compression, provided that $\mu_{ij} = -\varepsilon_i / \varepsilon_j$. Specimen **3**): similarly, Poisson´s ratio μ_{tp}, $\mu_{31} = \mu_{32}$, respectively, will be measured in a configuration when the loading force is perpendicular to the composite laminae. In the next graph, Fig.2, mean values from the first analysis [see Fig.1, specimen **1**)], are compared in dependence on various kinds of composite technology. Based on the



linear part, corresponding moduli of elasticity E_3 were assessed and the second knee of each graph yielded limit stress value σ_{3lim}.



applications	carbonization	carbonization + 3×impregnation	carbonization + 1×impregnation
E_3 [MPa]	801,0	1240,8	546,5
$\sigma_{3\,lim}$ [MPa]	-72	-201	-139

Fig. 2 Moduli of elasticity and stress values

Results and discussion

The experiments presented in this paper have had a pilot character. They have been designed to provide mechanical characteristics of C-C composite to be applied in FEM models of intervertebral cages. The problem is complicated due to the fact that C-C composite examined has been simultaneously developed aiming to match two important properties: i) suitable mechanical characteristics, to serve as implants, on one hand, and ii) a sufficient porosity, to enable a bone ingrowth, on the other hand. First experiments were carried out with thin samples loaded perpendicularly to its carbon fabric layers which resulted to loading rather the carbon matrix while its reinforcement played a little role. Due to a lack of superfluous samples which could serve for a proper microscope examination of polished sample sections in various loading stages, it has not been found out if the matrix has not been damaged at a certain load level. From that reason contemporary interpretation of the results obtained is as follows: The first (concave) knee of the curves can be attributed to an interface contact creation between the sample and the jaw fixations and the second (convex) knee can be explained either as yielding or destruction onset of the matrix. Nevertheless, there can be quite different interpretation: the matrix is being damaged from the very loading onset and the curves measured are due to a gradual contact increase of the parallel carbon fabric layers. These dilemma may be solved only after all the experiments and examinations planned have been carried out.

Conclusions

To eliminate problems exhibited at the PEEK cage experimental investigation, some relevant measures has been planned in further research (e.g., using a cementation of uneven parts, applying higher loading values, etc.). As far as the C-C composite, to be used as components in spine injuries treatment, is concerned, a complex experimental programme proposed will be carried out combined with FEM material models simulation.

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