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COMPOSITE MATERIAL BASED ON ARAMID FIBERS AND POLYSILOXANE MATRIX MODIFIED BY HYDROXAPATITE NANOPARTICLES

KOMPOZITNÍ MATERIÁL NA BÁZI ARAMIDOVÝCH VLÁKEN A POLYSILOXANOVÉ MATRICE MODIFIKOVANÉ HYDROXYAPATITOVÝMI NANOČÁSTICEMI

Abstract

Several materials have been used for constructing artificial bone substitutes. Each of these material types has its specific advantages and limitations. For a proper application it is important to match their mechanical and other chemical and physical properties. This study is aimed at verification of influence of hydroxyapatite nanoparticles additives, commonly used to improve the bioactivity of implants, on mechanical properties (namely ultimate strength in bending and modulus of elasticity in bending) of composite material potentially applicable in the bone surgery.

Abstrakt

Pro konstrukci umělých kostních náhrad se používá celá řada různých materiálů, každý z těchto materiálů má své specifické výhody i omezení. Pro úspěšnou aplikaci je důležité správně navrhnout jejich mechanické, chemické a fyzikální vlastnosti. Tato studie si klade za cíl ověření vlivu nanočásticového hydroxyaptitu, jako bioaktivní příměsi matrice, na mechanické vlastnosti (jmenovitě pevnost v ohybu a ohybový modul pružnosti) kompozitního materiálu perspektivně použitelného v kostní chirurgii.

1 INTRODUCTION

For construction of artificial bone substitutes, several materials have been used. Each of these material types has its specific advantages and limitations. It is important to match their mechanical and other chemical and physical properties. From a wide range of studies performed on various

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materials it follows that the bone tissue formation is influenced by several factors; porosity, wettability, chemical composition, rigidity etc. [1, 2]. This study objection is to present the influence of hydroxyapatite nanoparticles additives, commonly used to improve the bioactivity of implants, on mechanical properties (namely ultimate strength in bending and modulus of elasticity in bending) of composite material potentially applicable in bone surgery [3, 4].

2 MATERIALS AND METHODS

A composite material based on fabric reinforcement (Aramid balanced fabric, based on aromatic polyamide fibers HM 215, Hexcel, France) and polysiloxane matrix M130 (poly-dymethyl siloxane, Lucebni zavody Kolin, Czech Republic) was prepared; see Tab. 1.

Tab. 1 Monofile properties of fabric used

Monofile diameter [μm]	12
Density [g/cm^3]	1.44
Ultimate tensile strength [MPa]	3150
Young's modulus [GPa]	110

Hydroxyapatite (HAp) powder, particle size avg. 20-70 nm, was added into the matrix before impregnation in the amount of 0, 2, 5, 10, 15, 20 and 25 wgt% (HAp/matrix) (BABI-HAP-N20 AH, grains in ammonium hydroxide suspension Berkeley Advanced Biomaterials Inc., San Leandro, CA, USA), see Fig. 1. For this purpose, the homogenizer DI 18 Basic (IKA Werke GMbH) was used. A weighted amount of HAp was gradually inserted into a weighted amount of polysiloxane matrix M130, so that uniform dispersion of the HAp filler in the matrix (running speed of the homogenizer 17 500 1/min, dispersion time 6 hours) was achieved.

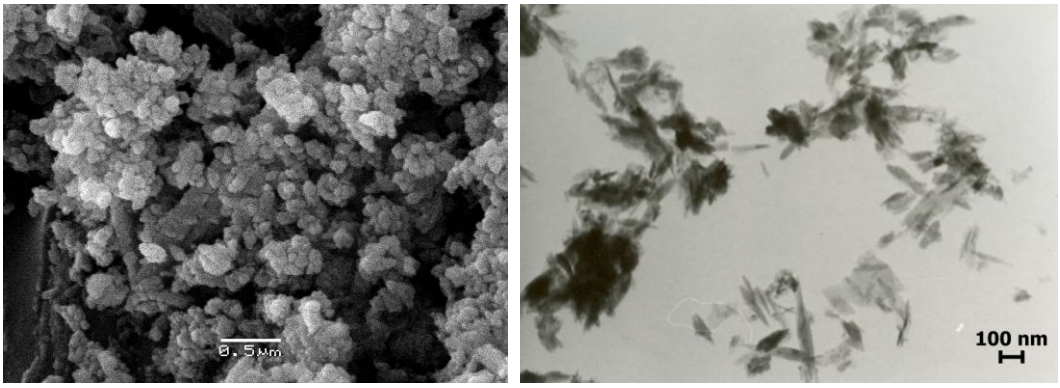

Fig. 1 SEM and TEM pictures of agglomerated needle-shaped nano HAp

After this procedure, the fabric was impregnated by the matrix/Hap blend and then, after 24 hours, cut into squared pieces with dimensions 118x118 mm. 11 impregnated layers were placed into the curing form with respect to the axis of fibers (each layer has a same orientation of the warp, with ply direction (0°) and the fill, with ply direction (90°)).The green composite was heated in the form at the temperature 135°C for two hours and then cured under pressure of 1.1 MPa at the temperature of 225°C in air atmosphere for 4.5 hours and finally hardened without applying the pressure at the temperature 250°C for 4 hours. This pressing cycle corresponds to an observed temperature viscosity rise of the matrix used. After curing, cured plates were cut with diamond saw to appropriate size according to further 4-point bending mechanical tests (see below). Ultimate strength in bending (*RfM*) and modulus of elasticity in bending (*Ef*) in the direction of the fiber axis were determined by a four-point bending setup in an Inspekt 100 HT material tester (Hagewald & Peschke, Germany) with respect to ISO 14125, 10 samples from each group were measured with dimensions 60x2.5x15mm

(length x thickness x width), crosshead speed 0.5 mm/min, load cell HT Beige 2kN, Maytec Germany.

3 RESULTS

Seven kinds of composite samples differing by HAp volume were examined. The open porosity and apparent density of all composite samples were measured according to ASTM C-373, see Tab. 2.

Tab. 2 The open porosity and apparent density of composite samples

wgt% (HAp/matrix)	porosity [%]	bulk density [g/cm^3]
0	14.54	1.18
2	18.03	1.12
5	17.84	1.14
10	15.36	1.19
15	14.30	1.28
20	12.09	1.36
25	14.32	1.32

The ultimate strength in bending (modulus of elasticity in bending)/HAp volume faction relationship were determined (see Fig. 2). The presence of HAp in composite matrix has, in general, a negative influence on mechanical properties (possibly due to a lower cohesion between layers). This fact can be favourable when looking for a sufficient compromise between mechanical properties comparable with those of human cortical bone and sufficient osseoconductivity. Higher volumes of HAp matrix additives (20, 25%) possibly influence the structure of cured matrix (see Fig. 3). In this case, the matrix seems to be prone to a brittle failure (becoming more ceramic), which could lead to a lower resistance to fatigue failure, which is one of limiting factors for applicability of implant materials.

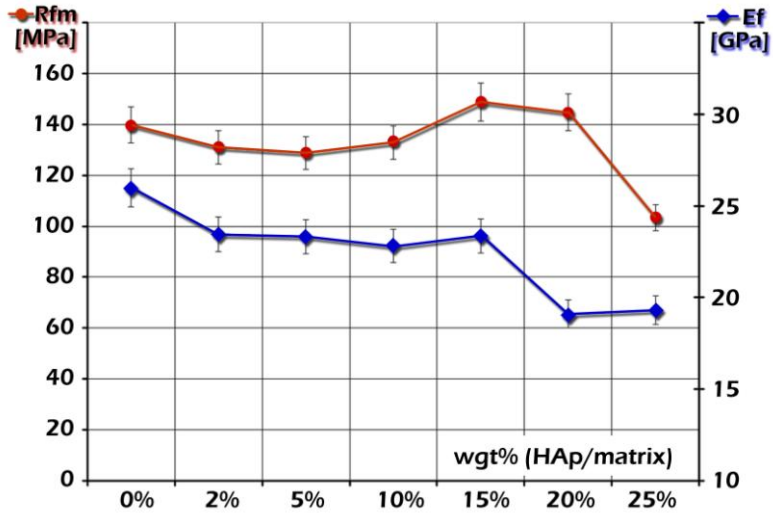

Fig. 2 Ultimate strength in bending *Rfm* and modulus of elasticity in bending *Ef* of composites with HAp nanopartricles

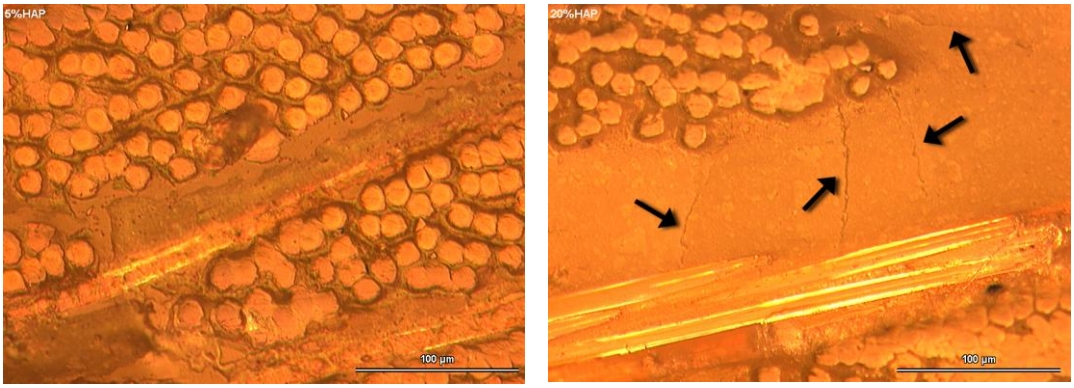

Fig. 3 Pictures of polished cross-section of composite with 5% HAp (left) and 20% HAp (right) illustrate multiple cracking in cured matrix with higher amount of HAp

4 CONCLUSIONS

We obtained ultimate strength in bending and modulus of elasticity in bending of composites based on aramid fabric and polysiloxane resin with various amount of HAp nanoparticles additives. It is important to match the compromise between sufficient mechanical properties and amount of bioactive additives. It seems that higher amount of additives should have a negative influence on mechanical properties. As a further step it will be necessary to define an amount of additives more precisely (step 1-2%) and also to compare different size of particles (nano vs. micro).

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REFERENCES

[1] RAMAKRISHNA S., MAYER J., WINTERMANTEL E. Biomedical applications of polymer-composite materials: a review. *Composite Science and Technology*. 2001, 61, pp. 1189-1224.

[2] NAKAMURA ET AL. A new glass-ceramic for bone replacement: Evaluation of its bonding to bone tissue. *Journal of Biomedical Materials Research*. 1985, 19, pp. 685-698.

[3] SUCHY T., BALÍK K., SOCHOR M., ČERNÝ M., HULEJOVÁ H. ET AL. Porous glass composites for hard tissue replacements. In *Human Biomechanics 2006 [CD-ROM]*. University of Technology, Brno, 2006, pp. 1-5. ISBN 80-214-3232-2.

[4] BALIK K., SOCHOR M., SUCHY T., CERNY M., HULEJOVA H. Bone plates based on glass fibers and polysiloxane. In *Journal of Biomechanics, Abstracts of the 5th World Congress of Biomechanics, Vol. 39, Suppl. 1)*, Elsevier, Berlin, 2006, p. S264. ISSN 0021-9290

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