MECHANICAL PROPERTIES OF COMPOSITES BASED ON GLASS FIBERS AND SILOXANES AS BIOMATERIAL

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Abstract

Nowhere is the ability to tailor the properties of materials having greater impact than in the medical devices market. Advanced coating technology, new knowledge of biocompatibility, and the ability to produce designer materials are creating a broad variety of important new medical innovations. New composite materials such as glass composites for implants applications are moving rapidly out of the laboratory and into the hospital and clinic. They can potentially be used in orthopedics in the form of substitutive or connective elements. Stress analysis, surface analysis and materials designs were performed to reach desired physical and biomedical properties. These properties are namely suitable mechanical characteristics, to serve as implant materials and a sufficient porosity, to enhance a bone growth.

Key words: *biomaterial, composite, glass, siloxane, mechanical properties*

Introduction

The composite materials proposed as substitutive or connective elements in orthopedics must be biocompatible and their mechanical properties should approach as much as possible the properties of the human bone (the strength characteristics should be at least the same and the modulus of elasticity should be close to the value characterizing the human bone).

However, by the biocompatibility is meant now not only a passive biocompatibility or an inertness that is the facilitation of the growth of the tissue around the implant without any signs of toxicity but especially the bioactivity, i. e. the assurance of a specific biological response on the interface of the material, resulting in the formation of a solid bond between the material and the tissue [1].

In the preceding projects where we have tested carbon - carbon composite materials as implants we have prepared materials with the strength in bending and the elasticity modulus similar to the human bone [2, 3, 4, 5]. These values - especially those of strength in bending - were attained by multiple impregnations from both liquid and gaseous phase. However, this procedure led at the same time to a significant decrease in open porosity with a prevailing pore dimension of about 40 µm, this size of pores giving no possibility of the downgrowth of the hard bone tissue. This is possible only in the case of the pores with a minimum size of 150 µm [6]. The implants with 250 µm pores had the strongest biomechanical strengths [8]. Moreover, the relatively complex preparation and the expensive components (the carbon fibers) increase significantly the price of these materials.

In order to obtain the bioactivity of the composite materials, materials based on bioglasses as reinforcement and thermoplastics (polysulfones, polyetheretherketones) as a matrix were prepared in abroad [9]. The prepared composites with reinforcement chopped or braided, combined with carbon fibers in order to increase their rigidity, exhibited according to their authors a good bioactivity. The proper bioactivity of the bioglasses is given by their chemical composition, especially by their content in the oxides SiO_2, Al_2O_3, P_2O_5, CaO and the alkalis. Hench presents in his papers [10, 11] the preparation of glasses, the chemical composition of which - especially the content in Ca and P - was similar to that of bone. These glasses guaranteed a solid bond between the bone and the implant. However, their preparation and the fiber formation proper are very difficult and exacting is according to our opinion also the preparation of the composites proper [11,9].

In the literature, we have found the application of siloxanes as biomaterials. In the publication[13] poly dimethyl siloxanes alone, hardened with peroxides, introduced for a longer time (up to 105 days) into laboratory rats are tested and in a further work [14] a composite membrane on the basis of polysiloxanes and cholesterol carbonate was prepared. The result of the experiments is the finding that hardened polysiloxane is biocompatible.

Glass fibers are the most common of all reinforcing fibers for polymeric matrix composites. Their main advantages are low cost, high tensile strength, high chemical resistance and good insulating properties.The use of the composite based on glass and polymer as biomaterial is demonstrated in the FIG. 1.

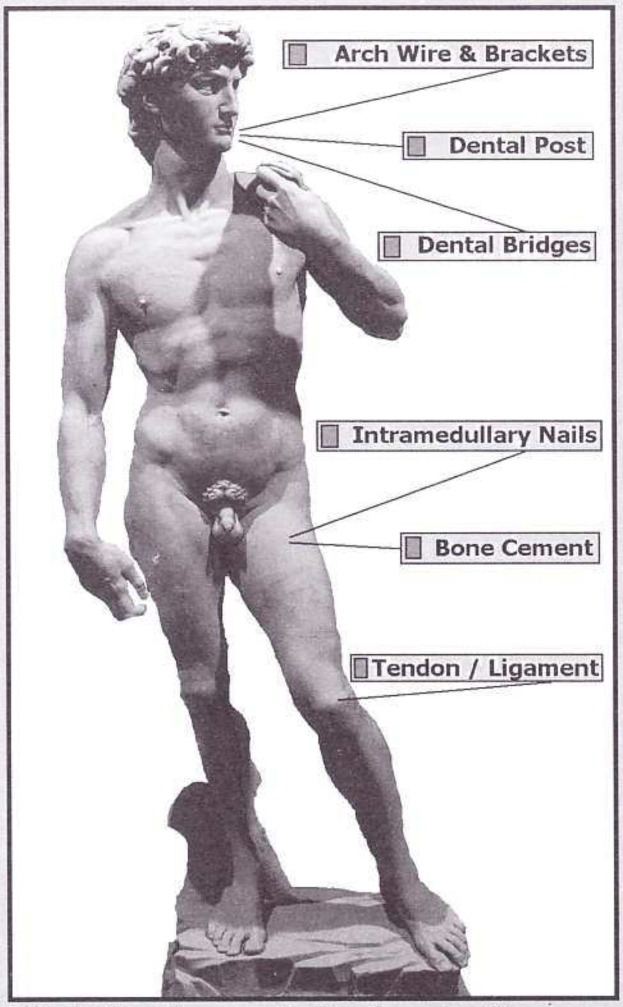

FIG. 1. Glass fibers application (based on 7)

In this study the preparation of glass-siloxane composites, their mechanical properties and surface character are shown.

Materials and methods

Properties of various glasses and fabrics are gathered in TAB.1.

The siloxane precursors LUKOSIL 901 and LUKOSIL M130 resins (commercial products of Lučební závody Kolín, Czech Republic) were used. The composites were prepared from plain-woven cloth V240 (E-Glass, VETROTEX, Litomyšl, Czech Republic), and from satin-woven fabric 21055 (R-glass, VETROTEX, Saint Gobain, France).

			E-Glass	R-Glass
Glass composition	SiO_2	[weight %]	53-57	58-60
	Al_2O_3	[weight %]	12-15	23.5-25.5
	CaO, MgO	[weight %]	22-26	14-17
	B_2O_3	[weight %]	5-8	-
	F_2	[weight %]	0-0.6	-
	Na_2O+K_2O	[weight %]	<1	-
	Fe_2O_3	[weight %]	-0.5	-
Mechanical properties	Virgin filament tensile test MPa]		3400	4400
	Impregnated strand tensile test *(calculated on fiber cross section)* [MPa]		2400	3400
	Tensile modulus	[GPa]	73	86
	Tenacity (sized yarns)	[cN/Tex]	Min. 50	
	Elastic recovery	[%]	100	100
Glass fabric	Weight	[g/m^2]	240	300
	Thickness	[mm]	0.3	0.22

TAB .1. Properties of glasses and glass fabrics

The soaked prepregs were stacked, cured at 250°C, then cut into pieces of the required size (40×8×2mm), and cured / pyrolyzed at 200-350°C in nitrogen.

The Young's modulus in tension and in-plane shear modulus were measured using the electrodynamic resonant frequency tester ERUDITE. The flexural strength was determined with groups of samples processed under identical conditions by a three-point bending arrangement on the material tester MINIMAT.

The character of surface was studied by using the image analysis system LUCIA.

Results and discussion

Mechanical testing of glass composite samples, dimensions of which enabled to use strain gauges, while applying loading forces in parallel direction to the composite laminae, has been prepared. More complex information about glass composite will be obtained (E, G, Poisson's ratio mtp, stress limit values s 1,3lim both in tension and compression, provided that mij = -ei /ej) by three-point bending tests, four-point bending tests, flexural tests and resonance measurements. To ensure a full contact between the tested samples and the hydraulic jaws, special fixtures were manufactured combined with bone cement. First results from mechanical tests are listed in the TABLE 2.

	E-Glass +L130	E-Glass +L901	R-Glass +L130	R-Glass +L901
Young's modulus E [GPa]	39.93	20.45	42.92	41.23
Shear modulus G [GPa]	2.39	2.77	3.17	4.60
Flexural strength Rm [MPa]	200.81	195.75	391.76	443.02

TAB. 2. Mechanical properties of glass composites

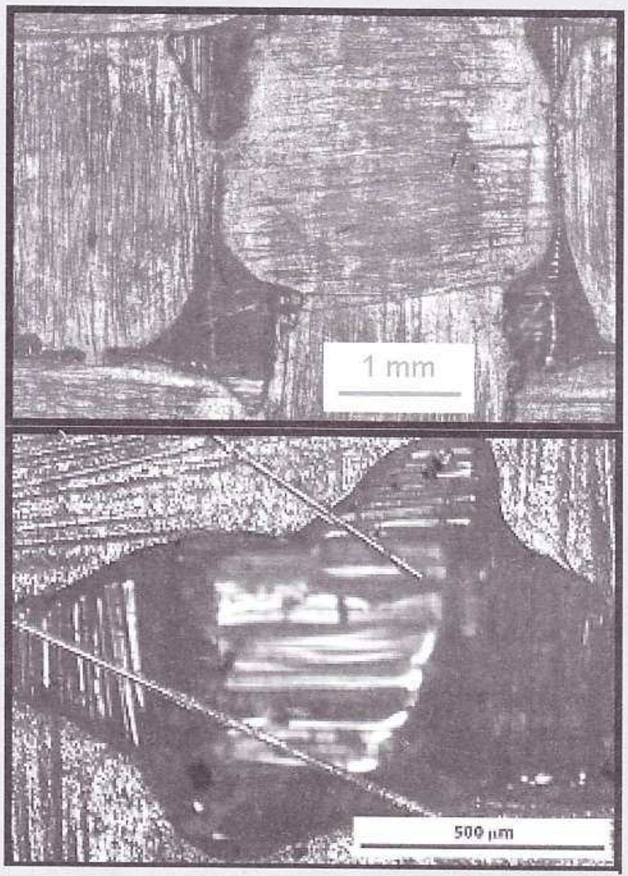

FIG. 2, 3. Photomicrographs of composite surface

If we compare the mechanical properties of both glass composites and carbon-carbon composites with mechanical properties of human bone (see TABLE 3), we can see first of all sufficient strength and a relatively low value of modulus of glass composites.

The Figures 2, 3 demonstrate the sufficient pore dimensions. This size of pores over, above cited, 250 µm is giving good presumption of the ingrowth of the hard bone tissue.

	Composites		Hard tissues [15]		
	R-Glass +L901	C/C (Toray800)	Cortical bone (longitudinal dir.)	Cortical bone (trasverse)	Enamel
Young's modulus E [GPa]	41.2	160.8	17.7	12.8	84.3
Shear modulus G [GPa]	4.6	-	-	-	-
Flexural strength [MPa]	443.0	110.6	-	-	-
Tensile strength [MPa]	-	-	133.0	52.0	10.0

TAB. 3. Comparsion of mechanical properties of various materials

Conclusion

Not only a composite material exhibiting high strength values has been looking-for. Based on a complex analysis, the glass composite exhibits a compromise between required both mechanical properties (a relatively sufficient strength value and a low modulus of elasticity, comparable with that of human bone, and biological properties (a sufficient porosity), which would be favorable for tissue and bone in growth, has been developed. Next step of our project will be also biotolerance testing. The biotolerance testing of our glass composites have two parts, tests in-vitro and tests in-vivo (implantation into rats) namely cytokine level observation (observation in the extract of newly formed tissue surrounding the implant the inflammatory cytokines interlukin-I (IL-1β) and the tumor-necrosis factor (TNF-α) and histological observation (standard histological examination (painted with haematoxylin-eosin), creation and a quality of capsular connective tissue, including inflammatory cells in the implant neighbourhood).

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