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(54) Title: THERMOPLASTIC POLYMER COMPOSITION FOR SKELETAL REPLACEMENTS AND METHOD OF ITS PRODUCTION

(57) Abstract: The invention concerns thermoplastic polymer compositions for skeletal replacements and methods of their production. The composition according to the invention consists of 12 - 91 wt.% of a polyolefm with the glass transition temperature higher than 320 K, which is an ethene - bicyclo[2.2.1]hept-2-ene copolymer with molar concentration of the latter at least 25 % and 75 % at most, of 2 - 72 wt. % of a polyolefm with the glass transition temperature lower than 250 K, which is (i) ethene homopolymer of density at least 0.92 g.cm^{-3} and 0.97 g.cm^{-3} at most or (ii) copolymer of ethene with an α-olefin selected from a group consisting of propene, but-1-ene, hex-1-ene, oct-1-ene and dec-1-ene, with density at least 0.85 g.cm^{-3} and 0.96 g.cm^{-3} at most or a mixture of ethene homopolymer (i) and ethene - α-olefin copolymer (ii) in any ratio, and of 5-50 wt.% of carbon fibres with the carbon content at least 94 wt.%, density at least 1.80 g.cm^{-3} and 1.92 g.cm^{-3} at most and a fibre diameter of at least 4 μm and 9 μm at most. The described composition is prepared by mixing in the melt a polyolefm with the glass transition temperature higher than 320 K and a polyolefm with the glass transition temperature lower than 250 K at a melt temperature of the stirred mixture of at least 430 K. The formed thermoplastic polymer composition is irradiated with γ-rays or accelerated electrons at a dose of at least 20 kGy and 250 IcGy at most, to advantage in inert atmosphere, whereupon the irradiated material is mixed in the melt with carbon fibres at a temperature of at least 430 K. The material can be stabilized against oxidative degradation by admixture of at least 0.1 wt.% of α-tocopherol.

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Thermoplastic polymer composition for skeletal replacements and method of its production

Technical field

The invention concerns thermoplastic polymer compositions for skeletal replacements and methods of their production for utilization in human and veterinary medicine.

Background art

Replacement of defective bone tissues by materials of nonbiological origin have been utilized in traumatology, orthopaedy and surgery for approximately hundred years. Originally, skeletal replacements were manufactured from appropriate metals, in the first place from alloys of gold and platin, later on from titanium and special alloyed steels. The last mentioned metal materials are utilized in construction of joint endoprostheses to date.
The development of medical techniques together with the research results in the field of biomechanics led in the last three decades to extension of applications of polymer materials. However, the choice of polymers suitable for production of skeletal implants is strictly limited by the requirement for their tolerance by living tissues. For this reason, first of all poly(methyl methacrylate) (PMMA), poly(tetrafluoroethene) (PTFE) and ultrahigh-molecular-weight polyethylene (UHMWPE) are utilized for bone tissue replacements at present.

The materials so far used for production of skeletal replacements are suitable in clinical practice but, at the same time, show certain drawbacks. The drawback all the materials have in common is their mechanical properties, diametrically different from mechanical properties of the bone tissue they replace. All metal materials exhibit Young moduli higher by several orders of magnitude than any bone tissue (for instance, the Young modulus of the femur amounts to ca 18-23 GPa whereas the Young modulus of alloyed steels is around 200 GPa); on the contrary, all hitherto used polymer materials show Young moduli lower by several orders of magnitude.
Great differences between stiffness in bending of rigid stems of implants and that of diaphyses (e.g., of femur) lead to the formation of a “stress shield”, which lowers common (natural) loading in bones. As a consequence of pronounced lowering of loading of corticalis in the diaphysis wall, local resorption of bone tissue occurs in many cases (even after several

years) and, subsequently, the stem stability in diaphysial channel is reduced. Natural transformation of diaphyses (with implanted stem) can be provided in certain limits by using composite stems with a gradient of elastic properties (gradient of elasticity moduli), having the surface lamella from a material with the same or near Young modulus as corticalis has (Petrtýl M., Pavlanský R.: Hip Implants, *US Patent* No. 4743263, May 1989; Petrtýl M., Jíra A.: Hip Replacements of the Second Generation, In: *Engineering Mechanics,* Vol. 11, No. 6, 2004, pp. 429-440; Petrtýl M. et al.: How to Ensure the Stability of Hip Replacements, In: Proc.: 15th Annual Meeting of the European Orthopaedic Research Society, June 2005, Lisabon, Portugal).

A prospective solution to the problem is the composites based on a polymer tolerated by living tissue and reinforced with appropriate high-modulus fibres (e.g. carbon fibres). Mechanical properties of a composite material can be controlled by its composition according to the requirements of the envisaged application. From the latest results of materials research follows that copolymers of ethene with bicyclo[2.2.1]hept-2-ene are an appropriate matrix for the composites. The polymers show relatively high toughness and it has been experimentally proved that they are well tolerated by living tissue. However, an essential drawback of the copolymers is their low toughness. The drawback can be eliminated by their modification with a polymer component, which would be dispersed in the above matrix.
The composition of the thermoplastic composition based on the above copolymer and method of its production and processing to polymer parts of skeletal replacements are the subject of the invention described hereinafter.

Disclosure of invention

The substance of the invention is a thermoplastic composition for skeletal replacements and method of its production. The composition consists of 12 - 91 wt.% of a polyolefin with the glass transition temperature higher than 320 K, represented by an ethene bicyclo[2.2.1]hept-2-ene copolymer with molar concentration of the latter at least 25 % and 75 % at most, of 2 - 72 wt. % of a polyolefin with the glass transition temperature lower than 250 K, which is (i) ethene homopolymer of density at least 0.92 g.cm^{-3} and 0.97 g.cm^{-3} at most or (ii) copolymer of ethene with an α-olefin selected from a group consisting of propene, but-1-ene, hex-1-ene, oct-1-ene and dec-1-ene, with density at least 0.85 g.cm^{-3} and 0.96 g.cm^{-3} at most or a mixture of ethene homopolymer (i) and ethene – α-olefin copolymer (ii) in any ratio, and of 5 – 50 wt.% of carbon fibres with the carbon content at least 94 wt.%, density at least 1.80 g.cm^{-3} and 1.92 g.cm^{-3} at most and a fibre diameter of at least 4 μm and 9 μm at most.

The above composition is prepared by mixing in the melt a polyolefin with the glass transition temperature higher than 320 K and a polyolefin with the glass transition temperature lower than 250 K at a melt temperature at least 430 K, irradiating the formed thermoplastic polymer composition with γ-rays or accelerated electrons at a dose of at least 20 kGy and 250 kGy at most, to advantage in inert atmosphere, and mixing the irradiated material in the melt with carbon fibres at a temperature of at least 430 K .

It is appropriate to stabilize the material against oxidative degradation by admixture of at least 0.1 wt.% of α-tocopherol in the last step of preparation.

The main benefit of the composition according to the invention and of the method of its preparation is the fact that it enables adjustment of mechanical properties of the material in a sufficiently broad range through modification of the contents of individual components so that the implants produced would show the same deformation behaviour as the parts of bones or also cartilages that should be replaced in specific applications. The hitherto known materials and methods of production of skeletal replacements do not make possible adjustment of mechanical properties in such broad range.

In addition, it was experimentally proved that ethene – bicyclo[2.2.1]hept-2-ene copolymers are well tolerated by living tissue. The supramolecular structure of blends of ethene – bicyclo[2.2.1]hept-2-ene copolymers with polyethylene or with copolymers of ethene and higher α-olefins, obtained by melt mixing, can be efficiently stabilized with an appropriate dose of ionizing radiation so that it does not change during subsequent melt processing.

In addition, blends of the given polymers, where the ethene – bicyclo[2.2.1]hept-2-ene copolymer forms a matrix, modified by ionizing radiation show, in comparison with non-irradiated blends of the same composition, pronouncedly higher toughness while keeping the same level of the other mechanical characteristics. In mixing the given polymer blends with mineral fibres as reinforcing additives, encapsulation of fibres with polymer-dispersed phase does not proceed in ionizing-radiation-modified blends, which is accompanied by a lowering of the reinforcing effect of fibres.

Examples

Example 1

Blends of ethene – bicyclo[2.2.1]hept-2-ene copolymer (component A, ethylene unit content 72.5 mol%, impact tensile strength 23 kJ.m^2, Young modulus 2600 MPa) and ethene – oct-1-

ene copolymer (component B, density 0.902 g.cm^{-3}) with the ratios A:B 70:30 (Blends 1-3) and 50:50 (Blends 4-6) were prepared by melt mixing. The mixing was performed in the W 50EH chamber of a laboratory mixer Brabender Plasti-Corder PLE 651 at 190 °C at the rotation rate 60 min^{-1} for 8 min (Blends 1,4). From the obtained material, plates of 1.5 mm thickness were prepared by pressing, which were subsequently exposed to a total dose of γ-radiation of 25 kGy (Blends 2,5). The irradiated material was again processed in the chamber of the laboratory mixer at 190 °C and 60 min^{-1} and stirred with 5 wt.% of carbon fibres of 7.2 μm diameter, length 6 mm and carbon content 95 % (Blends 3,6). Selected mechanical properties of the blends (measured at 23 °C) at different stages of the preparation of final materials are given in Table 1.

Table 1 Selected mechanical properties of ethene – bicyclo[2.2.1]hept-2-ene copolymer and ethene – oct-1-ene copolymer blends

Blend	Impact tensile strength [kJ.m^{-2}]	Young modulus [MPa]	Extensibility [%]	Tensile strength [MPa]
A:B = 70:30				
1	41	1300	5	35
2	52	1300	5	35
3	100	1350	7	39
A:B = 50:50				
4	38	580	12	17
5	65	590	17	17
6	185	650	75	24

Example 2

A blend with the A:B component ratio 70:30 was prepared using the procedure given in Example 1, which was subsequently irradiated with γ-rays in a total dose of 25 kGy. The thus modified material was processed in the chamber of a laboratory mixer with an admixture of 30 wt.% of carbon fibres (C) at 190 °C and at the rate 60 min^{-1} for 8 min. The composition of the resulting material is expressed by the weight ratio of components A:B:C = 49:21:30 (Blend 7). An analogous blend was prepared in parallel from the material that was not modified by radiation (Blend 8). The values of impact strength, impact tensile strength and

Young modulus (at 23 °C) as properties characterizing toughness and stiffness of the material are compared with the values for corresponding blends containing 5 % of carbon fibres.

Table 2 Effect of carbon-fibre reinforcement and radiation modificatiom on selected properties of of ethene – bicyclo[2.2.1]hept-2-ene copolymer and ethene – oct-1-ene copolymer blends

Blend	Impact strength Charpy [kJ.m^{-2}]	Impact tensile strength [kJ.m^{-2}]	Young modulus [MPa]
2	27	52	1300
7	28	57	6600
1	23	41	1300
8	11	23	6600

Industrial aplicability

The thermoplastic polymer composition according to the invention can be utilized in production of skeletal replacements for human and veterinary medicine.

CLAIMS

1. A thermoplastic polymer composition for skeletal replacements characterized in that it consists of 12 wt.%-91 wt.% of a polyolefin with glass transition temperature higher than 320 K, which is an ethene – bicyclo[2.2.1]hept-2-ene copolymer, with molar concentration of bicyclo[2.2.1]hept-2-ene at least 25 % and 75 % at most, of 2 wt.%-72 wt.% of a polyolefin with glass transition temperature lower than 250 K, which is (i) ethene homopolymer of density at least 0.92 g.cm^{-3} and 0.97 g.cm^{-3} at most or (ii) copolymer of ethene with an α-olefin, selected from the group consisting of propene, but-1-ene, hex-1-ene, oct-1-ene and dec-1-ene, of density at least 0.85 g.cm^{-3} and 0.96 g.cm^{-3} at most or a mixture of ethene homopolymer and ethene - α-olefin copolymer in any ratio, and of 5 wt.% - 50 wt.% of carbon fibres with the carbon content at least 94 wt.%, density at least 1.80 g.cm^{-3} and 1.92 g.cm^{-3} at most and the fibre diameter at least 4 μm and 9 μm at most.
2. The method of production of thermoplastic polymer composition for skeletal replacements according to Claim 1 characterized in that the polyolefin with glass transition temperature higher than 320 K and the polyolefin with glass transition temperature lower than 250 K are mixed in the melt at temperature of the stirred mixture at least 430 K, the formed thermoplastic polymer composition is irradiated with γ-rays or accelerated electrons at a dose of of at least 20 kGy and 250 kGy at most, whereupon the irradiated material is mixed in the melt with carbon fibres at the minimum temperature 430 K .
3. Method of production of thermoplastic polymer composition for skeletal replacements according to Claim 2 characterized in that the irradiation of thermoplastic polymer composition with γ-rays or accelerated electrons is performed in inert atmosphere.
4. Method of production of thermoplastic polymer composition for skeletal replacements according to Claim 2 characterized in that the material is stabilized against oxidative degradation in the course of the mixing of thermoplastic polymer composition with carbon fibres by an admixture of at least 0.1 wt.% of α-tocopherol.

INTERNATIONAL SEARCH REPORT

International application No
PCT/CZ2007/000007

A. CLASSIFICATION OF SUBJECT MATTER
INV. C08L23/02 A61F2/28

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
C08L A61F

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 4 743 263 A (PETRTYL MIROSLAV [CS] ET AL) 10 May 1988 (1988-05-10) cited in the application the whole document -----	1-4
A	US 3 494 897 A (REDING FREDERICK P ET AL) 10 February 1970 (1970-02-10) the whole document -----	1-4
A	US 3 162 698 A (BAUM BERNARD O) 22 December 1964 (1964-12-22) the whole document -----	1-4
A	GB 1 018 778 A (MONTEDISON SPA) 2 February 1966 (1966-02-02) the whole document -----	1-4

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
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