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(54) Title: ISOTOPICALLY LABELLED MATERIALS FOR DEGRADATION DETECTION

(57) Abstract: The invention relates to an isotopically marked material comprising a functional synthetic polymer and optionally a functional additive and to its use in the detection of material contamination or degradation or wear, preferably when said material is an industrial material, a space material or a prosthetic material.

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Isotopically labelled materials for degradation detection

FIELD OF INVENTION

The present invention belongs to the field of material contamination or degradation detection, particularly to the use of isotopically labelled materials for the detection of material contamination in industrial processes, space research or in biomedical applications.

BACKGROUND OF THE INVENTION

The space exploration and the search of life in other celestial bodies has suffered an exponential increase in the last 60 years. Technological advances have made it possible to set objectives and achieve goals that were unthinkable before 1957, the date on which the first successful satellite, Sputnik 1, was launched. This event launched the space race, and with it, a large number of missions that have explored planets, satellites and comets from our galaxy.

The beginning of these contacts brought with it concern about the possible contamination produced in the visited bodies (Forward contamination), and that received in the return missions (Backward contamination). To study how to minimize the effect of these processes and issue recommendations the COSPAR (Committee on space research) was formed in 1964. Its resolutions were ratified by the United Nations in the "External Space Treaty" of 1967. Space agencies have adopted these recommendations in their procedures and the Planetary Protection protocols are strictly followed in all space missions. The cleaning procedures and the control systems for biological, molecular and particle contamination are very rigorous and are present in all phases of the mission: design, manufacture, assembly, integration, testing, storage, transportation, preparation for launch, launch and orbit.

Especially sensitive to cross contamination are the scientific missions *in situ* whose objective is the search for life precursors. The analytical equipment shipped aboard the rovers and probes are increasingly sensitive and the detection range is becoming smaller (ppb). A natural pollution, or accidental, produced by the material transported from the Earth in a mission can produce a false positive in the search for life precursors, where biological traces as simple as C-H, C-O or C-N links are looked for.

Advances in polymer technology have allowed to improve the mechanical and thermal properties, which together with its lightness, has made polymers very interesting candidates for spatial use as structural materials. As functional materials its use is even more

widespread: wiring, adhesives, plastic connectors, lubricants or gaskets that are present in any mission.

However, the simple signals of the mentioned links could be detected in a large number of the polymers, which are the fundamental basis of their composition, and in case of
5 contamination, produce a false positive in the analysis of the samples.

US2010063208 A1 and US2010062251 A1 relate to taggant fibers which can be manufactured using polymeric materials. US2015377841 A1 disclose fibers which contain identification fibers, which are chemically marked or tagged. None of these documents disclose any material marked isotopically. Also, in these three documents, the marked fibers
10 are used specifically for tagging the material. However, the present invention relates to materials which do not incorporate any component specifically and only for marking or tagging the material.

SUMMARY OF THE INVENTION

The present invention provides a material which allows the detection of any contamination
15 or degradation or wear of said material in a simple and very reliable way. The inventors of the present invention have found that an isotopically marked functional material can be traced and, moreover, that its different components can be traced so as to identify if there has been any contamination or degradation of the material in general or of any of its components in particular.

20 In a first aspect, the present invention relates to a material comprising a synthetic functional polymer and optionally at least one functional additive, wherein said material is marked with at least one isotope of table 1, wherein the isotope or isotopes are present in a functional component of the material. Said functional component or components of the material where the isotope or isotopes are present is not used in the material for marking said material but
25 has another function in said material other than marking the material, such as a structural function, or a function such as that of a plasticizer, a flame retardant, a filler, an antioxidant, a metal scavenger, a UV protector, a photostabilizer, a heat stabilizer, an impact modifier, etc. Thus, the marked functional component is not present in the material only for the purpose of labelling or tagging the material.

30 DESCRIPTION OF THE INVENTION

In a preferred embodiment of the first aspect, the present invention relates to a material comprising at least one synthetic functional polymer and optionally at least one functional

additive, wherein said material is marked with at least one isotope of table 1, wherein the isotope or isotopes are present in a functional component of the material.

In a preferred embodiment of the first aspect, the material comprises more than one component and the same isotope is used for marking different components.

5 Table 1. Isotopes.

Isotopes						
¹ H	³⁶ Ar	⁶⁸ Zn	⁹⁷ Mo	¹²³ Sn	¹⁵⁰ Sm	¹⁷⁸ Hf
² H	³⁸ Ar	⁷⁰ Zn	⁹⁸ Mo	¹²⁰ Te	¹⁵² Sm	¹⁷⁹ Hf
³ He	⁴⁰ Ar	⁶⁹ Ga	⁹⁶ Ru	¹²² Te	¹⁵⁴ Sm	¹⁸⁰ Hf
⁴ He	³⁹ K	⁷¹ Ga	⁹⁸ Ru	¹²³ Te	¹⁵³ Eu	¹⁸¹ Ta
⁶ Li	⁴¹ K	⁷⁰ Ge	⁹⁹ Ru	¹²⁴ Te	¹⁵⁴ Gd	¹⁸² W
⁷ Li	⁴⁰ Ca	⁷² Ge	¹⁰⁰ Ru	¹²⁵ Te	¹⁵⁵ Gd	¹⁸³ W
⁹ Be	⁴² Ca	⁷³ Ge	¹⁰¹ Ru	¹²⁶ Te	¹⁵⁶ Gd	¹⁸⁴ W
¹⁰ B	⁴³ Ca	⁷⁴ Ge	¹⁰² Ru	¹²⁷ I	¹⁵⁷ Gd	¹⁸⁶ W
¹¹ B	⁴⁴ Ca	⁷⁵ As	¹⁰⁴ Ru	¹²⁴ Xe	¹⁵⁸ Gd	¹⁸⁵ Re
¹² C	⁴⁶ Ca	⁷⁴ Se	¹⁰³ Rh	¹²⁶ Xe	¹⁶⁰ Gd	¹⁸⁴ Os
¹³ C	⁴⁵ Sc	⁷⁶ Se	¹⁰² Pd	¹²⁸ Xe	¹⁵⁹ Tb	¹⁸⁷ Os
¹⁴ C	⁴⁶ Ti	⁷⁷ Se	¹⁰⁴ Pd	¹²⁹ Xe	¹⁵⁶ Dy	¹⁸⁸ Os
¹⁴ N	⁴⁷ Ti	⁷⁸ Se	¹⁰⁵ Pd	¹³⁰ Xe	¹⁵⁸ Dy	¹⁸⁹ Os
¹⁵ N	⁴⁸ Ti	⁸⁰ Se	¹⁰⁶ Pd	¹³¹ Xe	¹⁶⁰ Dy	¹⁹⁰ Os
¹⁶ O	⁴⁹ Ti	⁷⁹ Br	¹⁰⁸ Pd	¹³² Xe	¹⁶¹ Dy	¹⁹² Os
¹⁷ O	⁵⁰ Ti	⁸¹ Br	¹¹⁰ Pd	¹³⁴ Xe	¹⁶² Dy	¹⁹¹ Ir
¹⁸ O	⁵¹ V	⁸⁰ Kr	¹⁰⁷ Ag	¹³³ Cs	¹⁶³ Dy	¹⁹³ Ir
¹⁹ F	⁵⁰ Cr	⁸² Kr	¹⁰⁹ Ag	¹³² Ba	¹⁶⁴ Dy	¹⁹² Pt
²⁰ Ne	⁵² Cr	⁸³ Kr	¹⁰⁶ Cd	¹³⁴ Ba	¹⁶⁵ Ho	¹⁹⁴ Pt
²¹ Ne	⁵³ Cr	⁸⁴ Kr	¹⁰⁸ Cd	¹³⁵ Ba	¹⁶² Er	¹⁹⁵ Pt
²² Ne	⁵⁴ Cr	⁸⁶ Kr	¹¹⁰ Cd	¹³⁶ Ba	¹⁶⁴ Er	¹⁹⁶ Pt
²³ Na	⁵⁵ Mn	⁸⁵ Rb	¹¹¹ Cd	¹³⁷ Ba	¹⁶⁶ Er	¹⁹⁸ Pt
²⁴ Mg	⁵⁴ Fe	⁸⁴ Sr	¹¹² Cd	¹³⁸ Ba	¹⁶⁷ Er	¹⁹⁷ Au
²⁵ Mg	⁵⁶ Fe	⁸⁶ Sr	¹¹⁴ Cd	¹³⁹ La	¹⁶⁸ Er	¹⁹⁶ Hg
²⁶ Mg	⁵⁷ Fe	⁸⁷ Sr	¹¹³ In	¹³⁶ Ce	¹⁷⁰ Er	¹⁹⁸ Hg
²⁷ Al	⁵⁸ Fe	⁸⁸ Sr	¹¹² Sn	¹³⁸ Ce	¹⁶⁹ Tm	¹⁹⁹ Hg
²⁸ Si	⁵⁹ Co	⁸⁹ Y	¹¹⁴ Sn	¹⁴⁰ Ce	¹⁶⁸ Yb	²⁰⁰ Hg
²⁹ Si	⁵⁸ Ni	⁹⁰ Zr	¹¹⁵ Sn	¹⁴² Ce	¹⁷⁰ Yb	²⁰¹ Hg
³⁰ Si	⁶⁰ Ni	⁹¹ Zr	¹¹⁶ Sn	¹⁴¹ Pr	¹⁷¹ Yb	²⁰² Hg

³¹ P	⁶¹ Ni	⁹² Zr	¹¹⁷ Sn	¹⁴² Nd	¹⁷² Yb	²⁰⁴ Hg
³² S	⁶² Ni	⁹⁴ Zr	¹¹⁸ Sn	¹⁴³ Nd	¹⁷³ Yb	²⁰³ Tl
³³ S	⁶⁴ Ni	⁹³ Nb	¹¹⁹ Sn	¹⁴⁵ Nd	¹⁷⁴ Yb	²⁰⁵ Tl
³⁴ S	⁶³ Cu	⁹² Mo	¹²⁰ Sn	¹⁴⁶ Nd	¹⁷⁶ Yb	²⁰⁴ Pb
³⁶ S	⁶⁵ Cu	⁹⁴ Mo	¹²² Sn	¹⁴⁸ Nd	¹⁷⁵ Lu	²⁰⁶ Pb
³⁵ Cl	⁶⁴ Zn	⁹⁵ Mo	¹²⁴ Sn	¹⁴⁴ Sm	¹⁷⁶ Hf	²⁰⁷ Pb
³⁶ Cl	⁶⁶ Zn	⁹⁶ Mo	¹²¹ Sb	¹⁴⁹ Sm	¹⁷⁷ Hf	²⁰⁸ Pb
³⁷ Cl	⁶⁷ Zn					

In another preferred embodiment of the first aspect, the material comprises more than one component and wherein a different isotope is used for marking different components.

In a preferred embodiment of the first aspect, the isotope is introduced in a specific position
5 in a monomer of the synthetic polymer.

In a preferred embodiment of the first aspect, the at least one isotope is selected from ²H, ¹³C, ¹⁵N, ¹⁷O, ¹⁸O, ²⁹Si, ³⁰Si, ³³S, ³⁴S, ³⁶S, ³⁷Cl. These isotopes form covalent bonds in organic compounds.

The term “functional” as used herein means that the synthetic polymer or the additive’s
10 purpose or function is not exclusively marking the material, that is, the synthetic polymer or additive has a function other than marking the material. For example, the function of the synthetic polymer may be structural. For example, the function of the additive may be a plasticizer, a flame retardant, a filler, an antioxidant, a metal scavenger, a uv protector, a photostabilizer, a heat stabilizer, or an impact modifier. The term “functional” as used herein
15 should not be understood as “functional group” but as explained above.

The expression “present in a functional component of the material” also means that the component of the material which is isotopically marked has a function other than marking the material. For example, when the component that is isotopically marked is the synthetic polymer, this polymer may be a structural component, useful for its mechanical properties,
20 or a functional component, useful for its chemical, magnetic, electronic properties, etc., and this polymer will be useful for other reasons than for being marked.

The term “component” as used herein means any constituting part of a larger whole, any constituent. In the present description, the term “component” refers to the material and, therefore, refers to any constituting part of the material.

The term “marked” or “marking” as used herein means that the material in general and the marked component in particular, comprise a different isotopic ratio than the isotopic ratio present in the medium or environment where the material is used. For example, for space material to be used in Mars, the isotopic environment in the material will be different than the isotopic environment in Mars. For space material to be used in the Moon, the isotopic environment in the material will be different than the isotopic environment in the Moon. For a prosthetic material to be used in the human body, the isotopic environment in the material will be different than the isotopic environment in the human body. The skilled person is fully aware of how to prepare the materials of the present invention, once the particular isotopic environment for the material has been chosen (see for example Nikonowicz, E. P. et al. 1992 *Nucleic acids research*, 20 (17), 4507-4513; Schmidt, O., and Scrimgeour, C. M. (2001). *Plant and Soil*, 229(2), 197-202; Liu, L., and Fan, S. (2001) *Journal of the American Chemical Society*, 123(46), 11502-11503; Mulder, F. M. et al. 1998 *Journal of the American Chemical Society*, 120(49), 12891-12894; US 6,541,671; Park, S. et al (2012). *Nature communications*, 3, 638; Connolly, B. A., and Eckstein, F. (1984). *Biochemistry*, 23(23), 5523-5527; Crosby, S. R., et al. (2002). *Organic letters*, 4(20), 3407-3410; Yao, X. et al. (2003) *Journal of proteome research*, 2(2), 147-152).

The terms “labelled” and “marked” are used interchangeably in the present description.

The expression “isotopic environment” as used herein refers to the percentage of each isotope of each chemical element in a certain physical environment, i.e. in a certain planet, satellite, etc. The expression “different isotopic environment” as used herein means that upon detecting the percent of a certain isotope of a certain chemical element in the material and in a particular natural environment, different percentages will be obtained. For example, for a material marked with ^2H (deuterium) to be used in Mars, its minimum mark will be 5 times the abundance of ^2H in Mars, which is 0.3895 % of the Hydrogen atoms in the marked component of the material will be ^2H .

For example, the plasticizer dioctyl phthalate (DOP) can be added in a 0.1 weight % to the composition of a material comprising a synthetic polymer. If DOP is marked at the 50 % of a set atomic position, this means that this component of the material is marked and if it degasifies, the degraded component will be detected because of the different signals generated by this 50% of marked positions.

The present invention allows to have different marking in each component which allows to identify the component which is suffering degradation.

A material can be 100% traceable if all of its components are marked and each one is marked using a specific marking, which can be associated to a specific component or material upon detection.

In a preferred embodiment of the first aspect, the said material is an industrial material or a
5 space material or a prosthetic material.

In a preferred embodiment, the material is not a material susceptible of being falsified such as documents such as land titles, currency, or identification documents such as passports, etc.

The expression "industrial material" as used herein refers to any material suitable for
10 industrial applications. Materials suitable for industrial applications must be validated according to the characteristics of the specific field of use. Two examples of industrial material are:

- critical components of a loop system where the degradation of these components needs to be evaluated for maintenance or monitoring purposes.
- 15 • controlled environments (i.e.: clean rooms) where the contamination needs to be monitored and the contaminants need to be identified.

The expression "space material" as used herein refers to any material suitable for a space mission. Materials suitable for space missions must be validated according to the requirements of each mission in terms of space environment effects, such as vacuum, heat,
20 thermal cycling, radiation, debris, etc. and in terms of induced space environment effects, such as contamination, secondary radiations and spacecraft charging. These space environment effects are defined by the external physical world for each mission: atmosphere, meteoroids, energetic particle radiation, etc. The induced space environment is that set of environmental conditions created or modified by the presence or operation of
25 the item and its mission. The space environment also contains elements which are induced by the execution of other space activities (e.g. debris and contamination).

The expression "prosthetic material" as used herein refers to any material suitable for a use in a prosthesis, preferably in the animal body, more preferably in the human body. The prosthesis may be external or internal to the body. Materials suitable for being used in a
30 prosthesis are biocompatible and do not cause adverse local or systemic effects. The biocompatibility of the prosthetic material is tested according to ISO 10993. Also, USP Class VI standard may be used to determine the biocompatibility of the material. Preferably, ISO 10993 is used to test the biocompatibility.

In a preferred embodiment of the first aspect, at least 0.3 % of the atoms of the chemical element of the isotope are marked, in respect of the total number of atoms of that chemical element in the marked component of the material. Preferably, at least 0.5 % of the atoms of the chemical element of the isotope are marked, in respect of the total number of atoms of that chemical element in the marked component of the material. More preferably, at least 1 % of the atoms of the chemical element of the isotope are marked, in respect of the total number of atoms of that chemical element in the marked component of the material. In a more preferred embodiment, at least 2 % of the atoms of the chemical element of the isotope are marked, in respect of the total number of atoms of that chemical element in the marked component of the material. In an even more preferred embodiment, at least 5 % of the atoms of the chemical element of the isotope are marked, in respect of the total number of atoms of that chemical element in the marked component of the material. In another embodiment, at least 30 % of the atoms of the chemical element of the isotope are marked, in respect of the total number of atoms of that chemical element in the marked component of the material. The minimum marking of the material will depend on the technique intended to be used for detection and its sensitivity.

In a preferred embodiment of the first aspect, the isotopic mark is detected by FTIR, Raman, GC/MS, RMN-H, RMN-C, UV-visible spectroscopy. The isotopic mark is detected by any analytical technique that can detect the differences between the natural isotopic environment and the induced isotopic environment in the material. Preferably, the isotopic mark is detected by FTIR, Raman, GC/MS, RMN-H, RMN-C and/or UV-visible spectroscopy. More preferably, the isotopic mark is detected by Raman or GC/MS.

The materials of the present invention are characterized physico-chemically analysing their TGA, DSC, degree of crystallinity, glass transition temperature, gel permeation chromatography (GPC), FTIR, Raman and H-NMR. The degradation/contamination/wear of the materials of the present invention can be detected by means of the same analytical techniques used in the rover of the Exomars 2020 mission: Raman, GC/MS, etc. For example, the analytical techniques used in Martian rovers to search organic life signatures are gas chromatography with mass spectroscopy (GC/MS), laser desorption with mass spectroscopy (LD/MS) and Raman spectroscopy.

For those materials to be used in space, said materials will undergo the relevant spatial validation tests, required for all materials that participate in space missions, and which are determined by the type of mission, the function of the component, and its exposure to environmental agents.

For the materials described in the present invention, the rules of the ESA (European Space Agency) have been followed, and the validation tests have been those determined by the following standards:

- ECSS-E-ST-10-03C, "Space Engineering-Testing".
- 5 • ECSS-Q-ST-70C, "Space product assurance- Materials, mechanical parts and processes".

For using the material of the invention as a prosthetic material, the detection of the material degradation by LC/MS technique offers high sensitivity, area selectivity and the ability to discriminate between release products originating from the prosthetic material and those naturally present in biological fluids. In the manufacturing of the prosthetic material there are following main steps: compounding, solution mixing, powder mixture and sintering. The material can be fully labelled or only labelled in layers, for example, multilayer coating could be used with labelled layers as degradation witness. In a particular embodiment, the prosthetic material has at least one witness layer where the structural polymer is marked.

10

15 In another embodiment, the prosthetic material has at least one witness layer where a functional additive is marked. The amount of marked atoms (ratio of isotopic labelling) will depend on the strategy used (full marking/labelling or multilayer marking/labelling) and the sensitivity of the detection method used. The manufacturing and labelling technique is adapted and depends on the thermal properties of the synthetic polymer or polymers in the material. For example, for fluorinated polymers it is preferred to use a mixing powder and further sintering. The temperature profile of the process varies from 60 – 450 °C and the pressure, from 1 bar to 1,500 bar. For using the material of the invention as a prosthetic material, said materials must match the usual standards for this kind of devices and must fulfil the requirements of the validation tests established for each particular case.

20

25 An advantage of the present invention is the early and non-invasive detection of the degradation of an implant or a medical device, for example simply analysing a blood sample.

In a preferred embodiment of the first aspect, the synthetic polymer is an addition polymer or a condensation polymer. Preferably, the synthetic polymer is a polyolefin, a polyester, a polyurethane, a polyimide, a polyacrylate, a polysiloxane, a polyepoxide, a fluorinated polymer or a combination thereof. more preferably, the synthetic polymer is polyethylene (PE), polyethylene terephthalate (PET), polyamide (PA), ethylene tetrafluoroethylene (ETFE), polytetrafluoroethylene (PTFE), perfluoroalkoxy alkane (PFA),

30

polyetheretherketone (PEEK), polyethersulphone (PES), polysulfone, polyetherimide (PEI) or a copolymer or terpolymer thereof.

Examples of synthetic bioabsorbable polymers that may be used for prosthetic materials are polyglycolide, or polyglycolic acid (PGA), polylactide, or polylactic acid (PLA), poly ϵ -caprolactone, polydioxanone, polylactide-co-glycolide, e.g., block or random copolymers of
5 PGA and PLA, and other commercial bioabsorbable medical polymers. Preferred is spongy collagen or cellulose.

In a preferred embodiment of the first aspect, the material is a plastic, an adhesive, a coating, a varnish, a tape, a film, a paint, an ink, a lubricant, a potting, a sealant, a foam, a
10 rubber, a wire or a cable.

In a preferred embodiment of the first aspect, the material is an artificial heart, artificial heart valve, implantable cardioverter-defibrillator, cardiac pacemaker, coronary stent, an artificial bone, an artificial joints, pin, rod, screw, plate, a biodegradable medical implants, a contraceptive implant, a breast implant, a nose prosthesis, an ocular prosthesis or an
15 injectable filler.

In a second aspect, the present invention relates to the use of the material of the first aspect in the detection of material contamination or degradation or wear. For example, for space material, the present invention relates to the use of said material for the detection of any material contamination. For prosthetic material, the present invention relates to the use of
20 said material for the detection of its degradation. For industrial materials, the present invention relates to the use of said material for the detection of the material wear.

In a third aspect, the present invention relates to the use of the material of the first aspect for marking a composite material. Preferred composite materials comprise at least one of carbon fibre, polyethylene, polypropylene, nylon or kevlar. Preferably, the composite
25 material comprises a binder and reinforcement fibres and/or particles. Said binder and/or reinforcement fibres and/or particles could be also polymeric.

In a preferred embodiment of the first aspect of the present invention, the material comprises different components and all the marked components are marked with the same isotope.

30 In another aspect, the present invention relates to the use of a non polymeric compound suitable for being a functional component of a material of the first aspect and which is

marked with at least one isotope of table 1, for detecting contamination, degradation or wear of a material.

EXAMPLES

In order to provide a better understanding of the invention, the following is a detailed explanation of some of the preferred embodiments of the invention, which is provided to give an illustrative example of the invention but which, by no means, should be considered to limit the same.

Example 1

As an example of isotopically labelled structural or functional material for the application of space contamination detection, PET polymers (Polyethylene terephthalate) have been synthesized and have the same technical characteristics as the PET used as the calibrator of the Raman spectrometer that will go aboard the Exomars.. These polymers have been synthesized starting from:

- Precursor monomer 1: Ethylene glycol and its deuterated namesake (ethylene-d₄ glycol)
 - Precursor monomer 2: terephthaloyl chloride and its deuterated namesake (terephthaloyl-d₄ chloride)
 - Solvents: chloroform/H₂O
 - Additives: Surfactant Hexadecyltrimethylammonium bromide (CTAB).
 - NaOH is added as a base.
- The synthesis has been carried out by additive polymerization (polycondensation in interface), in a two-phase system composed of an organic and an inorganic phase, with the following conditions:
- Temperature: 50 °C
 - Stirring: ≈ 500 rpm.
 - Pressure, vacuum: atmospheric pressure.
 - Catalyst: Not used.
 - Time: ≈ 20 hours.

- Type of atmosphere: air.
- molar ratio of the monomers: 1:1.

The monomers were added in a staggered manner in two independent phases. The interfacial polymerization proceeded then in the following way:

- 5
- First, the deionized H₂O was stirred together with the suitable amount of NaOH. When dissolved, ethylene glycol and surfactant (CTAB) were added. When a homogeneous solution was achieved (between 2-10 minutes), the next phase, consisting in the corresponding amount of terephthaloyl chloride dissolved in chloroform, was added.
 - The two phases were mixed and maintained with vigorous stirring for approximately 20
- 10 hours at 50 °C.

The ratio of isotopically labelled polymer was graduated by employing different mixtures of the monomers and their deuterated analogues. For the example, 5 different compositions were made:

- 0% labelling: 1X mol of terephthaloyl chloride + 1Y mol of ethylene glycol.
- 15
- 10% labelling: 0.9X mol of terephthaloyl chloride + 0.1X mol of terephthaloyl-d₄ chloride + 0.9Y mol of ethylene glycol + 0.1Y mol of ethylene-d₄ glycol.
 - 25% labelling: 0.75X mol of terephthaloyl chloride + 0.25X mol of terephthaloyl-d₄ chloride + 0.75Y mol of ethylene glycol + 0.25Y mol of ethylene-d₄ glycol.
 - 50 % labelling: 0.5 X mol of terephthaloyl chloride + 0.5 X mol of terephthaloyl-d₄ chloride
- 20 + 0.5 Y mol of ethylene glycol + 0.5 Y mol of ethylene-d₄ glycol.
- 100% labelling: X mol of terephthaloyl-d₄ chloride + Y mol of ethylene-d₄ glycol.

Purification:

The purification of the resulting material was carried out in the following manner:

- Once the reaction time has elapsed, the resulting product was washed three times filtered
- 25 and collected. The purified product was then introduced in a stove until it was completely dried.

After this purification, it was necessary to carry out a bakeout to release the non-crosslinked monomers, and the residues of additives and solvent, typical in materials for space use.

Example 2: Synthesis of deuterium marked polyethylene terephthalate.

Over a solution of 0.001 to 17 kg of NaOH (0.30 mol/L) in water, 0.0035 to 500 mol of a mixture of ethyleneglycol and ethylene-d₄ glycol (ratio from 0 to 100 %; total concentration 0.41 mol/L) was added under stirring at a moderate speed. Subsequently, 0.01 mol-% of
5 phase transfer catalyst (for example, tetrabutylammonium bromide) dissolved in 0.001 to 10 liters of water were added. A mixture of terephthaloyl chloride and terephthaloyl-d₄ chloride (ratio from 0 to 100 %; molar ratio diol/diacid chloride 1:1) was dissolved in chloroform (ratio water/chloroform 70:30). The organic phase was then added over the aqueous layer under vigorous stirring and mixing continued for 5 to 60 minutes. Acetone
10 was added to the reaction vessel and the polymer was filtered off and washed with acetone to remove unreacted monomers. The material was subsequently washed three times with water and then filtered off. The final product was dried to constant weight in a vacuum oven at 40 °C.

Example 3: Synthesis of deuterium marked polyethylene.

15 Ethylene and ethylene-d₄ were introduced at different ratios and at a moderate flow to a stirred solution containing a 1 to 1 mixture of TiCl₄ and AlEt₃ in hexanes under N₂ atmosphere. When the reaction mixture became thick, the mixture was hydrolyzed by addition of several amounts of ethanol. The resulting material was subsequently washed several times with ethanol, filtered and dried.

20 Example 4: identification of marked PET

The PET polymer was marked using deuterium in the 100% of the hydrogen atomic positions of both precursor monomers (ethyleneglycol-d₄, and terephthaloyl chloride-d₄).

In order to detect/identify the marked PET, different techniques were used:

Raman spectroscopy

25 Raman spectroscopy is a non-destructive technique that does not need the previous preparation of the sample.

For this study the Raman spectrometer used was a RAMAN Horiba XPlora with Laser: 532 nm (Green) and Confocal microscope 10x.

30 We found that the isotopic substitution of deuterium (²H) instead of protium (¹H) in the 100% of hydrogen positions (aliphatic and aromatic) in PET caused little differences in many of the detected signals, but in those in which the hydrogen interaction was higher, the shift of

the signals was more notorious and easy to differentiate in the marked sample. Some examples of the most representative were the following:

Table 2. Summary of main differences detected by marking the PET polymer.

Interpretation of band	Protium (cm ⁻¹)	Deuterium (cm ⁻¹)
C-H stretching aromatic	3089	2302, 2285
C-H stretching aliphatic	2973, 2944, 2928, 2854	2218, 2150, 2107
Ring C ₁ -C ₄ stretching	1615, 1310, 1192, 800, 701	1575, 1024, 847, 756, 689, 622
CH ₂ bending and CCH bending in the ethylene glycol segments	1462, 1418	1125, 1000
O-CH ₂ and C-C stretch of the Trans ethylene glycol unit	1002	893

- 5 Only the deuterated signals (Table 2) appeared in the spectrum, clearly differentiated from the analogous protium examples that did not appear in that case. The ratio of the intensity of equivalent signals must be proportional to the ratio of the marked:non-marked positions.

In the case of 50% of marked positions in both precursor monomers, the protium and deuterium signals will appear in the spectrum with same intensity, but keeping the shift that
10 allows to differentiate.

Gas chromatography and mass spectrometry (GC/MS)

50 mg of the powdered 100% marked PET was dissolved in 1 ml of acetone for HPLC (≥99.9%).

The GC/MS system used was a Varian Saturn 2200. The parameters of the method were:

- 15
- Chromatographic parameters: Column WCOT Fused Silica Rapid-MS, 10 m x 0,53 mm, od: 0,25 μm; 40°C (8 min), and then increase to 250 °C at 10 °C/min. to keep at 250 °C during 37 min. Injector 1177 a 280 °C and 1:5 split (1 μl injected). Carrier gas: Helium at 1.0 ml/min.
 - MS parameters: ion trap, with ionization mode: electronic impact (EI), scanning in
20 the range 30-650 M/z, 2 scan/second.

1 μl of the PET/acetone solution was injected directly in the 1177 injector of the GC, using a 5 μl Hamilton syringe.

As it happened in the Raman study, only the mass of the deuterated fragments (table 3) appeared in the chromatogram.

The +1(M/z) caused by every deuterium introduced instead of a protium has an accumulative effect, and in the PET case, the 8 marked position generates a +8 (M/z) for the molecular ion, and at least +4(M/z) in the most of identification fragments:

Table 3. Summary of main differences in the mass (M/z) of fragments detected by marking the PET polymer.

Fragment	Protium (cm ⁻¹)	Deuterium (cm ⁻¹)
[CH ₂ -OH] ⁺	31/33	33/35
[CH ₂ -OH] ₂ ⁺	62	66
Ring: [C ₆ H ₄] ⁺	76	80
[C ₆ H ₄ -CO] ⁺	104	108
[C ₆ H ₄ -COO-CH ₂ -CH ₂] ⁺	148	156
[C ₆ H ₄ -COO-CO] ⁺	149	153
Molecular ion [M] ⁺	193	201

In the case of 50% of marked positions in both precursor monomers, the protium and deuterium signals appear in the chromatogram with same intensity. Since the isotopic differences do not affect significantly the interaction of compounds with the chromatographic column, the separation was not possible (even for longer and soft methods) and the retention time was almost the same.

To solve this, the GC/MS systems allows the selective plot of the preferred masses. Protium and deuterium signals (table 3) could be plotted separately and compare the number of accumulated counts of every species.

The ratio of the intensity of the accumulated counts of the masses detected must be proportional to the ratio of the marked:non-marked positions.

Example 5: identification of functional additives

Three additives of common polymeric use are presented as examples of identification by GC/MS. The methodology of study and identification will be the same as for PET:

Diethyl phthalate (DEP)

DEP is used as plasticizer.

Gas chromatography and mass spectrometry (GC/MS)

The +1(M/z) caused by every deuterium introduced instead of a protium has an accumulative effect, and in the Dioctyl-Phthalate-d₃₈ (DOP) case, the 38 marked positions generates a +38 (M/z) for the molecular ion, and at least +4(M/z) in the most of identification fragments:

Table 4. Summary of main differences in the mass (M/z) of fragments that can be detected by marking the DOP.

Fragment	Protium (cm ⁻¹)	Deuterium (cm ⁻¹)
[(CH ₂) ₂ -CH ₃] ⁺	43	50
[(CH ₂) ₃ -CH ₃] ⁺	57	66
[(CH ₂) ₄ -CH ₃] ⁺	71	82
Ring: [C ₆ H ₄] ⁺	76	80
[C ₆ H ₄ -COO-CO] ⁺	149	153
[C ₆ H ₄ -COO(CH ₂) ₇ CH ₃ -COO] ⁺	279	300
Molecular ion [M] ⁺	390	428

Decamethyltetrasiloxane

10 Decamethyltetrasiloxane is used as adisitive in adhesives and lubricants.

Gas chromatography and mass spectrometry (GC/MS)

The +1(M/z) caused by every deuterium introduced instead of a protium has an accumulative effect, and in the decamethyltetrasiloxane-d₃₀ case, the 30 marked positions generates a +30 (M/z) for the molecular ion, and at least +9(M/z) in the most of identification fragments:

Table 5. Summary of main differences in the mass (M/z) of fragments that can be detected by marking the decamethyltetrasiloxane.

Fragment	Protium (cm ⁻¹)	Deuterium (cm ⁻¹)
[(CH ₃) ₃ Si] ⁺	73	82
[(CH ₃) ₃ Si-(CH ₃) ₂ SiO] ⁺	147	162
[((CH ₃) ₂ SiO) ₂ -(CH ₃)SiO ₂] ⁺	207	222
[(CH ₃) ₃ Si-((CH ₃) ₂ SiO) ₃] ⁺	295	322
[M] ⁺	310	340

Benzotriazole

Benzotriazole is used as UV photostabilizer.

Gas chromatography and mass spectrometry (GC/MS)

- 5 The +1(M/z) caused by every deuterium introduced instead of a protium has an acumulative effect, and in the Benzotriazole-d₄ case, the 4 marked positions generates a +4 (M/z) for the molecular ion, and at least +3(M/z) in the most of identification fragments:

Table 6.- Summary of main differences in the mass (M/z) of fragments that can be detected by marking the decamethyltetrasiloxane.

Fragment	Protium (cm ⁻¹)	Deuterium (cm ⁻¹)
[(CH) ₃] ⁺	39	42
[(CH) ₄] ⁺	52	56
[(CH) ₄ -C] ⁺	64	68
[(CH) ₄ -C ₂ -NH] ⁺	91	95
[M] ⁺	119	124

CLAIMS

1. A material comprising a synthetic functional polymer and optionally at least one functional additive, wherein said material is marked with at least one isotope of table 1, wherein the isotope or isotopes are present in a functional component of the material and wherein the
5 at least one isotope is selected from ^2H , ^{13}C , ^{15}N , ^{17}O , ^{18}O , ^{29}Si , ^{30}Si , ^{33}S , ^{34}S , ^{36}S , ^{37}Cl .
2. The material according to the preceding claim, wherein said material comprises more than one component and wherein the same isotope is used for marking different components.
3. The material according to claim 1, wherein said material comprises more than one
10 component and wherein a different isotope is used for marking different components.
4. The material according to any one of the preceding claims, wherein the isotope is introduced in a specific position in a monomer of the synthetic polymer.
5. The material according to any one of the preceding claims, wherein said material is an industrial material or a space material or a prosthetic material.
- 15 6. The material according to any one of the preceding claims, wherein at least 0.3 % of the atoms of the chemical element of the isotope are marked, in respect of the total number of atoms of that chemical element in the marked component of the material.
7. The material according to any one of the preceding claims, wherein the isotopic mark is detected by FTIR, Raman, GC/MS, RMN-H, RMN-C, UV-visible spectroscopy.
- 20 8. The material according to any one of the preceding claims, wherein the synthetic polymer is an addition polymer or a condensation polymer.
9. The material according to any one of the preceding claims, wherein the synthetic polymer is a polyolefin, a polyester, a polyurethane, a polyimide, a polyacrylate, a polysiloxane, a polyepoxide, a fluorinated polymer or a combination thereof.
- 25 10. The material according to any one of the preceding claims, wherein the synthetic polymer is polyethylene (PE), polyethylene terephthalate (PET), polyamide (PA), ethylene tetrafluoroethylene (ETFE), polytetrafluoroethylene (PTFE), perfluoroalkoxy alkane (PFA), polyetheretherketone (PEEK), polyethersulphone (PES), polysulfone, polyetherimide (PEI) or a copolymer or terpolymer thereof.

11. The material according to any one of claims 1 to 10, wherein said material is an artificial heart, artificial heart valve, implantable cardioverter-defibrillator, cardiac pacemaker, coronary stent, an artificial bone, an artificial joints, pin, rod, screw, plate, a biodegradable medical implants, a contraceptive implant, a breast implant, a nose prosthesis, an ocular
5 prosthesis or an injectable filler.
12. Use of the material according to any one of claims 1 to 11 in the detection of material contamination or degradation or wear.
13. Use of the material according to any one of claims 1 to 11 for marking a composite material.
- 10 14. The use according to the preceding claim, wherein the composite material comprises at least one of carbon fibre, polyethylene, polypropylene, nylon or kevlar.

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2019/066777

A. CLASSIFICATION OF SUBJECT MATTER
 INV. C08K5/12 C08K5/3475
 ADD. C08L23/06 C08L31/06

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)
 C08K C08L

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 practicable, search terms used)
 EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2010/063208 A1 (MERCHANT TIMOTHY P [US] ET AL) 11 March 2010 (2010-03-11) claims 1-21 -----	1-14
X	US 2010/062251 A1 (MERCHANT TIMOTHY P [US] ET AL) 11 March 2010 (2010-03-11) claims 1-23 -----	1-14
X	US 2015/377841 A1 (GAYNOR SCOTT GREGORY [US] ET AL) 31 December 2015 (2015-12-31) paragraph [0157] - paragraph [0199] -----	1-14

Further documents are listed in the continuation of Box C.

See patent family annex.

* Special categories of cited documents :

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- "O" document referring to an oral disclosure, use, exhibition or other means
- "P" document published prior to the international filing date but later than the priority date claimed

- "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
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- "&" document member of the same patent family

Date of the actual completion of the international search 11 July 2019	Date of mailing of the international search report 23/07/2019
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Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Authorized officer Scheid, Günther
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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No PCT/EP2019/066777

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