

Biodegradable linear random copolyester and process for preparing it and use of the same

Technical field

The present invention relates to a biodegradable linear random aliphatic/aromatic copolyester, in particular, to a biodegradable aliphatic/aromatic copolyester of high molecular weight and narrow molecular weight distribution, and to process for preparing it and use of the same.

Background art

At present, aromatic polyesters such as polyethylene terephthalate (PET), polybutylene terephthalate (PBT), polypropylene terephthalate (PPT) as engineering materials have been widely applied to various fields in daily life of human, which can be made into various materials such as fibers, beverage bottles and films. However, these polymers substantially cannot be degraded in nature, and can be very resistant bacterial or fungal attack. Until now, no bacteria or enzyme is observed to be able to erode pure aromatic polyesters (PET, PBT). These polyesters are difficult to be degraded in water. The service life of PET can be up to 16-48 years, and PET fiber can exist in human/animal body for 30 years. Thus, "white pollution" resulted from these polymers is one of fatal disasters facing human, and it is urgent to develop biodegradable materials. Aliphatic polyesters are getting more and more attention owing to their excellent biocompatibility and biodegradability, non-toxicity of polymers and degraded products thereof, and etc. They have been applied to biomedical materials (skeleton fixing and supporting materials, drug controlled-release materials, nerve guide and artificial blood vessel, suture line and etc.) and environment-friendly materials (trash bag, shopping bag, food packaging, dishware, agricultural mulch film, domestic bottles and jars, fishing gears and etc.). However, compared with aromatic polyesters as engineering materials, the

use of aliphatic polyesters as materials are limited due to their defects such as low melting point, weak mechanical property and high price. Therefore, the development of aliphatic-aromatic copolyesters, which combined the excellent use and processing properties of aromatic polyesters with the excellent biodegradability of aliphatic polyesters, is a hotspot regarding degradable materials.

In recent years, aliphatic/aromatic copolyesters have been commercialized at abroad, mainly including Ecoflex from BASF AG., Germany; Eastar Bio from Eastman Co., USA; Bionelle from Showa Co., USA (whose resins are provided by Showa Highpolymer Co., Japan, and SK Chemicals Co., Korea), Sky Green BDP from SK Chemicals; Biomax from Dupont Co., and etc.

Since these copolyesters are prepared via polycondensation, in which distilled fractions come out, it is difficult to prepare a high-molecular weight product, and in general only the product having a molecular weight of tens of thousands can be prepared. Owing to the low molecular weight, the mechanical properties of the product can hardly meet the standard in term of non-degradable materials that are widely used at present. Thus, it becomes more important to prepare a high-molecular weight copolyester product having qualified mechanical and processing properties. In U.S. Pat. No. 5,817,721, 5,889,135, 6,018,004, 6,046,248 and 6,114,042, BASF AG set forth that the addition of an anhydride, ether or isocyanate having multiple (at least three) functional groups reactive with polyester as a chain extender can obviously increase the weight-average molecular weight (may be up to one hundred of thousands) of the obtained copolyester, but the number-average molecular weight is not increased to such an extent as the weight-average molecular weight, and the molecular weight distribution of the product substantially becomes broader (3.5-8). The obtained product has a long-chain branching structure, which goes against further processing. Moreover, the chain extender added is directly linked to the long chain of the polymer, which makes the

polymer's structure become complicated and impure, and it is also hard to be removed.

The preparation of the polyesters prepared by polycondensation, such as polyethylene terephthalate (PET), polybutylene terephthalate (PBT) and polypropylene terephthalate (PPT), undergoes two steps comprising: esterification or interesterification of terephthalic acid or ester-forming derivatives thereof with aliphatic diol, wherein the esterification is carried out at high pressure, and the interesterification is carried out at atmospheric pressure; and vacuum polycondensation of the esterified or interesterified product. The two steps are generally carried out separately, and two polymerization autoclaves are needed therefor.

The catalyst systems used in the preparation of polyesters by polycondensation are diversified, almost concerning all subgroup A and B elements in Periodic Table of Elements except for halogen elements and inert elements. Those having the best catalytic effect may be generalized into the following three kinds: Ti-series, Sb-series and Ge-series. Ti-series element as catalysts has high catalytic activity, but the polyester product obtained has poor stability and yellow color. When Sb-series element is used as catalysts, the polymerization reaction goes steady. At present, 80% polyester products are prepared by using Sb-series catalyst at home and abroad. However, since Sb element is not in favor of environmental protection owing its toxicity, the service field of the polyester products prepared thereby is limited. Ge-series catalyst is one kind of polyester catalysts having the best comprehensive effects, but it cannot be widely used due to its high price.

In U.S. Pat. No. 5,817,721, BASF AG discloses a biodegradable polyester, which is obtained by mixing batch-wise aromatic dicarboxylic acid or ester-forming derivatives, aliphatic diol, and aliphatic dicarboxylic acid or ester-forming derivatives, and allowing the mixture to react in the presence of Sn compounds, Ti compounds and the like as esterification, interesterification

and polycondensation catalysts.

As disclosed in US6,018,004, US6,046,248 and US6,114,042, the preparation processes of polyesters in BASF AG are mostly carried out by two-steps in two polymerization autoclaves. Firstly, adipic acid is esterified with 1,4-butanediol (BDO) in the presence of tin dioctoate as a catalyst thereby obtaining an esterified product. Then, the esterified product as above obtained, dimethyl terephthalate (DMT), BDO, and tetrabutyl orthotitanate (TBOT) are simultaneously added to another reactor, and after finishing the interesterification between DMT and BDO, the system undergoes polycondensation in vacuum. The molecular weight of the polyester product obtained is not high, the number-average molecular weight (M_n) being about 1×10^4 , and the weight-average molecular weight being about 3×10^4 . If an anhydride, ether or isocyanate having multiple (at least three) functional groups reactive with polyester is added as a chain extender to the aforesaid second step, the weight-average molecular weight of the obtained copolyester can be obviously increased, but the number-average molecular weight is not increased to such an extent as the weight-average molecular weight, and the molecular weight distribution of the product substantively becomes broader (3.5-8).

Currently, the preparation of polyester by polycondensation generally includes three reaction stages, i.e., esterification, interesterification and polycondensation. In general, monomers and esterification or interesterification catalyst are simultaneously added to a polymerization autoclaves; after finishing esterification or interesterification (which is determined upon the distilled fractions), the esterified or interesterified product and polycondensation catalyst are simultaneously added to another polymerization autoclaves for polycondensation in vacuum.

The preparation of polyester by polycondensation is a relatively mature process route. Currently, the compounds of Ti, Zn and etc. and the compounds of heavy metals such as Pb, Sn, Sb and Cd are mostly used as catalysts at the

stages of esterification, transesterification and polycondensation. The former compounds easily result in serious side reactions, and the polyester product obtained has poor stability and yellow color; and the latter compounds have some toxicity, thus the use field of the polyester products obtained is limited. Although germanium oxide catalyst system has relatively better effect, it is difficult to be widely used owing to its high price. Thus, it is a hotspot for study in polyester industry to develop a novel catalyst system having good effect and low price.

In recent years, the use of rare earth(RE) compounds as catalysts has been widely concerned by scholars at home and abroad. There are many relevant techniques with respect to the preparation of polyester using La-series metal catalysts, e.g., CN1,112,573A, EP0,626,425 and CN1,446,837A. In the patent application No. CN1,112,573A, Enichemu Co., Italy, discloses the use of La-series metal compound, their metal salt, metal composite salt or salt-containing complex as catalyst, thereby obtaining a thermoplastic aromatic polyester having high resistance to degradation at molten state. In European patent application EP0,626,425, La-series metal composite salt is used as a catalyst for producing a thermoplastic aryl polycarbonate/aryl polyester component, with the thermoplastic component obtained having improved mechanical, thermal and electrical performances and relatively higher stability. In Chinese patent application CN1,446,837A, a La-series metal catalyst for preparing polyester is disclosed, said catalyst including components R1 and R2, wherein R1 is La-series metal halides and/or La-series metal complex, and R2 is La-series metal hydroxide, and the mixture of both can enable the transesterification to carry out rapidly and stably.

Our country is enriched with RE elements, accounting for about 80% of world reserves. Although it is well known that the use of RE compounds as polyester catalysts can increase the rate of polymerization, the concrete process and the apolegamy of catalyst are yet to be further studied. In the technique of

polyester preparation, there still exist many shortcomings such as complicated operation process and relatively broader molecular weight distribution of the polymerized product. Thus, it is desired to provide a process for preparing polyester using novel RE catalyst system and capable of simplifying the present polyester preparation process and reducing the occurrence of side reactions.

At present, all polymerization catalyst systems used for preparing biodegradable aliphatic/aromatic copolyesters by polycondensation in the prior art are titanium alkoxide, alkyl tin, germanium oxide and etc., for example, tetrabutyl orthotitanate, titanium isopropoxide and etc. as disclosed in □ Nihon Yukagakkaishi□ (1999, 48(9), p911-915), European patent EP1,106,640A2, and Germany patent DE19,923,053A1, n-butyl tin as disclosed in Korea patent KR9,709,332B1, germanium compounds as disclosed in Japanese patent JP2,004,018,674A2, and so on. As above described, the catalyst systems commonly used in polyester still have the various defects appeared in the preparation of polyester, such as resulting in product of yellow color and serious side reactions.

To sum up, the existing catalysts for polyesters have many shortcomings including low polymerization rate, serious side reactions, toxicity, product of yellow color and etc. Apart from these, the shortcomings such as complicated operation process and relatively broader molecular weight distribution of polymerized product further exist in the technique of preparing biodegradable copolyesters.

The object of the present invention is to obtain biodegradable copolyesters of high molecular weight and narrow molecular weight distribution.

Another object of the present invention is to provide a process for preparing polyester in the presence of a RE compound catalyst component.

Description of figures

Fig. 1 is ¹H NMR spectrum of copolyester product of DMT/ADP = 1/1 of

the present invention.

In the four peaks of abcd (a: 4.41 ppm, b: 4.35 ppm, c: 4.12 ppm, d: 4.06 ppm), a and d respectively correspond to homopolymerized chain segments, b and c respectively correspond to copolymerized chain segments. The molar ratio of the two monomers in the polymer is 50:50, and the chain segments where the two monomers directly link with each other account for 50% of the total polymer chain segments, which illustrates that the copolyester is a statistically random copolymer.

Fig. 2 is the structural formula of poly(butylene adipate).

Fig. 3 is the structural formula of poly(butylene terephthalate).

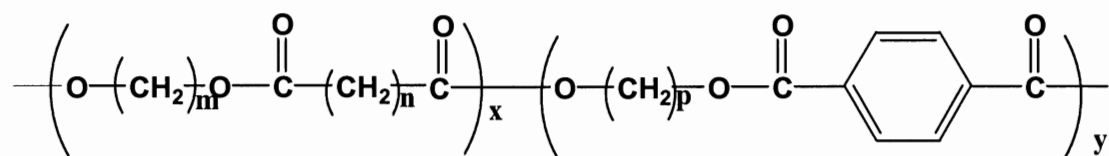
Fig. 4 is the structural formula of poly(butylene terephthalate-co-butylene adipate).

Fig. 5 is the DSC curve of the copolyester product of the present invention.

Contents of the invention

The term “biodegradable” used herein refers to that, under the action of microorganism, organic compound is decomposed into carbon dioxide (CO₂), water (H₂O) as well as mineralized inorganic salt(s) of element(s) contained therein and new biomass.

The biodegradable aliphatic/aromatic copolyester described herein is a random and linear aliphatic/aromatic copolyester, which comprises the following structural unit:



wherein m is an integer of 2 to 10, n is an integer of 0 to 8, p is an integer of 2 to 10, m, n and p being same or different, x is an integer of 1 to 10, and y is an integer of 1 to 10. Preferably, m is an integer of 2 to 4; n is an integer of 2 to 4; p

is an integer of 2 to 4; x is an integer of 1 to 3; and/or y is an integer of 1 to 2. As determined by GPC method, its weight-average molecular weight M_w is 100,000-600,000 g/mol, preferably 100,000-300,000 g/mol; and its molecular weight distribution is 1.2-3, preferably 1.5-2.5.

The aliphatic/aromatic copolyester described herein has a melting temperature range of preferably 20 to 185°C, and a glass temperature of preferably -55 to -7°C.

The biodegradable copolyester described herein can be used for preparing profiles, films, fibers or coatings. The biodegradable copolyester having high molecular weight can be prepared herein by adding a RE compound as catalyst as well as controlling the feed ratio of monomers/catalyst and the relevant process parameters in the absence of any chain extender. The product obtained has a molecular weight distribution of less than 3, and is in a linear structure. The compositional structure of the copolymer can be strictly controlled via adjusting the feed ratio, so that a statistically random copolymer can be prepared.

The present invention further relates to a process for preparing polyester, which comprises the steps of:

1) adding the following monomers and an optional catalyst component Cat1 to a reactor to carry out interesterification and/or esterification: (a) aromatic dicarboxylic acid, ester thereof, anhydride thereof, or mixture thereof, (b) aliphatic diol, alicyclic diol or mixture thereof, and (c) aliphatic dicarboxylic acid, alicyclic dicarboxylic acid, ester thereof, anhydrides thereof, or mixture thereof;

wherein the molar ratio of the monomer (a) to monomer (c) is 0:100-100:0;

2) prepolymerizing the reaction system obtained in step 1) under vacuum; and

3) adding a catalyst component Cat2 to the prepolymerized product obtained in step 2) to carry out polycondensation under vacuum, thereby

obtaining the desired polyester;

wherein, the catalyst component Cat1 is selected from the group consisting of the compounds of metals Ti, Sb and Zn, and mixtures thereof;

the catalyst component Cat2 is selected from the group consisting of the compounds of RE metal Ln and mixtures thereof, said RE metal Ln being selected from the group consisting of La-series elements, Sc and Y and combinations thereof.

When an aliphatic/aromatic copolyester is prepared, in the step 1), the aromatic monomer (a) may firstly react with the diol monomer (b), followed by adding the aliphatic monomer (c); or the aliphatic monomer (c) may firstly react with the diol monomer (b) followed by adding the aromatic monomer (a). Preferably, in the step 1), the catalyst component Cat1, and the monomers (a) and (b) firstly react by adding them to a reactor, followed by reacting with the monomer (c) to be added. The latter is more favorable to the sufficient proceeding of interesterification and esterification.

In one embodiment described herein, the monomers (a) and (b) along with Cat1 are firstly added to a reactor, and undergo esterification or interesterification at a temperature of preferably 150-230°C. When the distilled fraction as collected attains above 90% of its theoretical amount, the monomer (c) was added to the system, which thereafter undergoes the second-step esterification or interesterification at a temperature of preferably 160-250°C. Then, the system enters into the next step of prepolymerization when the distilled fraction as collected again attains above 90% of its theoretical amount.

The above two steps of esterification or interesterification may be carried out under atmospheric pressure, vacuum or superatmospheric pressure condition, preferably under atmospheric pressure.

Preferably, the prepolymerization of the step 2) is carried out at a temperature of 190-250°C and a vacuum pressure of 200-600 Pa, preferably 200-300 Pa for 1-3 h, preferably 1-2 h; or the step 3) is started after the small

molecules (including the unreacted monomers) in the reaction system of step 2) are almost completely evacuated and the temperature of fraction is kept constant. In step 3), catalyst component Cat2 is added to the reaction system.

In the step 3), the polycondensation is carried out at a temperature of preferably 200-300°C, more preferably 220-280°C, and a vacuum pressure of preferably ≤ 300 Pa, more preferably ≤ 200 Pa, for preferably 3-8 h.

All pressures concerned therein are gauge pressures.

A single-autoclave operation may be adopted in the process for preparing polyester described herein, i.e., the steps 1), 2) and 3) are carried out in the same autoclave.

In one preferred embodiment of the process described herein, the molar ratio of the monomer (a)/monomer (c) is 0:100-65:35, preferably 35:65-60:40; the molar ratio of the monomers (a)+(c)/monomer (b) is 1:(1.0-3.0), preferably 1:(1.0-2.0), more preferably 1:(1.1-1.5), even more preferably 1:(1.2-1.4); and the molar ratio of the catalyst system/the monomers (a)+(c) is 1:(500-10,000), preferably 1:(1,000-3,000).

In one preferred embodiment of the process described herein, the monomer (a) is selected from the group consisting of p-phenylene dicarboxylic acid, ester thereof or anhydride thereof, preferably terephthalic acid or dimethyl terephthalate; the monomer (b) is selected from the group consisting of C₂-C₆ aliphatic diol, C₅-C₁₀ alicyclic diol and mixtures thereof, preferably 1,4-butanediol, 1,3-propanediol or ethylene glycol; and the monomer (c) is selected from the group consisting of C₃-C₁₀ aliphatic dicarboxylic acid, C₅-C₁₀ alicyclic dicarboxylic acid, ester thereof, anhydrides thereof and mixtures thereof, preferably adipic acid, sebacic acid or succinic acid.

In one preferred embodiment of the process described herein, the monomer (a) is selected from the group consisting of terephthalic acid, ester thereof, anhydride thereof or mixtures thereof; the monomer (b) is selected from the group consisting of C₂-C₆ aliphatic diol, C₅-C₁₀ alicyclic diol or mixtures thereof;

and the monomer (c) is selected from the group consisting of adipic acid, ester thereof, anhydride thereof or mixtures thereof. In which, the molar ratio of the monomer (a)/monomer (c) is (5-75):(25-95), and the molar ratio of the monomers (a)+(c)/monomer (b) is 1:1-1:2. Preferably, in which, the molar ratio of the monomer (a)/(c) is (25-65):(35-75), and the molar ratio of the monomers (a)+(c)/monomer (b) is 1:1.2-1:1.5.

In one preferred embodiment of the process described herein, the catalyst component Cat 1 is selected from the group consisting of $M(OR_2')_x$, M_2O_x , $M(R_1'COO)_x$ and mixtures thereof, preferably selected from the group consisting of titanium alkoxide $Ti(OR_2')_x$, antimony acetate, zinc acetate, zinc oxides, antimony oxides, titanium oxides, mixtures thereof, more preferably selected from the group consisting of tetrabutyl orthotitanate, titanium isopropoxide, titanium dioxide, antimony trioxide, antimony acetate, zinc acetate and mixtures thereof; and the catalyst component Cat2 is selected from the group consisting of RE-metal's inorganic halides LnX_3 , carboxylates $Ln(R_1COO)_3$, alkoxides $Ln(OR_2)_3$, aryloxides $Ln(OAr)_3$, acetylacetonates $Ln(a_c a_c)_3$, hydrates thereof and mixtures thereof, preferably selected from the group consisting of RE-metal's inorganic halides LnX_3 , alkoxides $Ln(OR_2)_3$, aryloxides $Ln(OAr)_3$, acetylacetonates $Ln(a_c a_c)_3$ excluding samarium acetylacetonate $Sm(a_c a_c)_3$, and mixtures thereof;

Preferably, the molar ratio of Cat2/Cat1 is 5:95-100:0, more preferably 1:3-3:1, even more preferably 2:3-3:2;

In which, the RE metal Ln is preferably selected from the group consisting of La, Ce, Pr, Nd, Td, Yb, Dy, Sm, Sc and combinations thereof, more preferably selected from the group consisting of La, Ce, Pr, Nd, Sc and combinations thereof;

X is a halogen ion, preferably chlorine ion or bromine ion, and $a_c a_c$ is an acetylacetone group;

R_1 and R_1' are selected from C_1 - C_3 alkyl, R_1 , R_1' being same or different;

R_2 and R_2' are selected from C_3 - C_6 alkyl, R_2 , R_2' being same or different, preferably, R_2 is isopropyl, n-butyl or isopentyl;

Ar is selected from C_1 - C_4 alkyl substituted phenyl, preferably 2,6-di-tert-butyl-4-methylphenyl or 4-butylphenyl;

M is metal Ti, Sb or Zn, and x is 2, 3 or 4.

In one preferred embodiment of the process described herein, the catalyst component Cat1 is selected from the group consisting of tetrabutyl orthotitanate, titanium isopropoxide, titanium dioxide, antimony trioxide, antimony acetate, zinc acetate and mixtures thereof; and the catalyst component Cat2 is selected from the group consisting of RE inorganic halides LnX_3 , carboxylates $Ln(R_1COO)_3$, alkoxides $Ln(OR_2)_3$, aryloxides $Ln(OAr)_3$, and mixtures thereof; and the molar ratio of Cat2/Cat1 is 2:3-3:2;

in which, the RE metal Ln is selected from the group consisting of La, Ce, Pr, Nd, Sc and combinations thereof, and X is chlorine ion or bromine ion;

R_1 is ethyl or propyl, and R_2 is isopropyl, n-butyl or isopentyl;

Ar is 2,6-di-tert-butyl-4-methylphenyl or 4-butylphenyl.

The catalyst used herein is a single-component catalytic system of non-toxic or low-toxic RE compounds, or a multiple-component composite catalytic system of RE compounds and other metal compounds, which is favorably used for preparing biodegradable aliphatic/aromatic homo- and co-polyesters. The catalyst system may thus be a single-component Cat2, or a multiple-component composite system of Cat2 and Cat1.

The RE compounds as the catalyst component Cat2 of the catalyst system described herein may be prepared by the methods of synthesizing or treating RE compounds as disclosed in the prior art, e.g., the methods disclosed in the documents «J. Inorg. Nucl. Chem.» (1962, 34, p387), «Polymer» (2001, 42, p7511), «Inorganic Chemistry» (1970, 9, p2505), and «J. Chem. Soc., Chem. Commun.» (1983, p1499), as mentioned in the following Examples.

The compounds of Ti, Sb and Zn as the catalyst component Cat1 of the

catalyst system described herein may be commercial products, as mentioned in the following Examples.

Unless identified otherwise, the percentages and ratios used herein are all on the basis of weight.

All the publications mentioned are incorporated herein for reference in their entirety for all purposes.

The biodegradable copolyester described herein has the following features:

1) as being prepared in the absence of additives such as chain extender and stabilizer, the copolyester product is pure;

2) both the number-average and weight-average molecular weights of the copolyester product are obviously increased, with a molecular weight distribution being less than 3;

3) the compositional ratio of the copolyester product can be strictly controlled by adjusting the feed ratio of monomers, the compositional ratio of the copolymer is substantially equal to the feed ratio of monomers;

4) the copolyester product is in a long chain random linear structure, which is in favor of degradation and combination of excellent properties of two homopolymers; and

5) the copolyester product has mechanical properties up to or exceeding those of LDPE product, a relatively broader use temperature range (with better performances than those of the product having same components disclosed in U.S. Pat. No. 5,889,135 to BASF AG), and excellent processability.

The present process for preparing copolyester described herein has the following features:

1) the operation process is simplified by using a single-autoclave operation; the side reactions are reduced, and the polyester product's color is obviously improved;

2) the catalyst system used herein is a high-efficiency, non-toxic or low-toxic catalyst system, which can obviously increase the polymerization rate

with the polycondensation time being reduced from 10 h to 3-8 h in comparison with the single-component titanium compound catalyst system; at the same time of increasing the weight-average molecular weight, the number-average molecular weight of the polyester product is also increased, with its molecular weight distribution not being broaden; meanwhile, the reaction course is steady, and easily to be controlled;

3) the molecular weight of the polymerized product can be obviously increased in the absence of any chain extender; thus, the polyester product is pure, and free of additives such as chain extender and stabilizer; and

4) the process described herein is particularly suitable for preparing polyester having an aliphatic/aromatic molar ratio of 35-100:65-0, and the polyester product obtained thereby can be completely biodegraded within eight months.

Mode of carrying out the invention

The raw materials used in Examples of the present invention are as follows:

DMT: dimethyl terephthalate, CP degree, Beijing Xingjin Chemical Plant, China

ADP: adipic acid, AP degree, Shanghai Chemical Reagent Co., China Medical Group

BD: butanediol, AP degree, Beijing Yili Fine Chemicals Co., Ltd, China.

SCN: succinic acid, AP degree, Sanyi Chemicals Co., Ltd, Shenzhen city, China.

Acetic acid: 50%, Beijing Chemical Reagent Co., China

Stearic acid: AP degree, Beijing Chemical Reagent Co., China

Tetrabutyl orthotitanate: CP degree, Beijing Chemical Reagent Co., China

Zinc acetate: AP degree, Beijing Chemical Reagent Co., China

RE oxides: a purity of 99.5%, Beijing Xinhua Reagent Factory, China

RE chloride hydrates: CP degree, Beijing Xinhua Reagent Factory, China

2,6-di-tert-butyl-4-methylphenol: CP degree, Shanghai Chemical Reagent Co., China Medical Group

Isopropanol: AP degree, Beijing Chemical Plant, China

Sodium: Beijing Jinlong Chemical Reagent Co., Ltd., China

The methods for determining relevant data in examples of the present invention are as follows.

The compositional components of the polymer are determined by nuclear magnetic resonance (NMR) using Bruker Avance DMX500 model superconductive NMR spectrometer (^1H NMR: 500 MHz) at 25°C, with CDCl_3 as solvent, and TMS as internal standard.

The molecular weight and molecular weight distribution of the polymer are determined by gel permeation chromatograph (GPC) using Waters-208 instrument (Waters 2410 RI detector, a flow rate of 1.5 ml/min, and a temperature of 30°C), with THF as solvent, and the molecular weight calibrated by styrene standard sample.

The viscosity number (VN) is determined in a 0.005 g/ml polymer solution of o-dichlorobenzene/phenol in a weight ratio of 50/50 at 25°C, according to the test standard GB/T 17932-1999.

The yellow index is determined by using TC-PIIG full-automatic colorimeter according to the method described in GB 2409-1989.

The glass temperature (T_g) and melting temperature (T_m) of the polymer are determined by differential scanning calorimetry (DSC) using Perkin Elmer Pyris 1 analyzer, each sample being heated from -100°C to 250°C, and undergoing heating and scanning twice, with the heating rate of 20°C/min.

The tensile property of the polymer is determined according to the method described in ASTM D638-03.

The biodegrading characteristics of the polyester are tested by embedding-in-compost process. Polyester sample is hot pressed to form a film (10-20 μm), which is then cut into sample pieces of 2 cm x 2 cm, the sample

pieces so obtained are embedded in a culture dish packed with compost soil, and then the culture dish is put into an incubator under constant temperature and humidity. The humidity is kept at about 50%, and the temperature is kept at $58 \pm 2^\circ\text{C}$. The weight losses of the sample pieces are determined periodically.

Examples

The following examples further demonstrate the preferred embodiments of the present inventions. All the examples are merely illustrative, not interpreted as limiting to the present inventions.

Unless identified otherwise, each steps involved in the preparations of the catalysts or polyester are all conducted under atmospheric pressure or ambient temperature.

Examples A1-6 Preparation of RE catalyst component Cat2

Example A1 Preparation of anhydrous lanthanum chloride (LaCl_3) (cf. J. Inorg. Nucl. Chem., 1962, 34, 387)

10 g La_2O_3 was dissolved with excess amount of HCl. The obtained solution was concentrated by heating (temperature $\geq 100^\circ\text{C}$) prior to adding metered NH_4Cl (the molar ratio of $\text{NH}_4\text{Cl}/\text{La}_2\text{O}_3$ was 3/1) to it. The excess acid was evaporated by carefully heating (temperature $\geq 100^\circ\text{C}$), thereby obtaining a solid of $\text{LaCl}_3 \cdot n\text{H}_2\text{O} + \text{NH}_4\text{Cl}$. The solid was milled before being added to a quartz sublimation tube, and then the tube was vacuum supplied till a pressure of less than 5 mmHg. The tube was slowly heated to 400°C in a tubular furnace, with the vacuum pressure held for 1 h. The sublimation tube was cooled down to room temperature under vacuum, argon was filled to the sublimation tube before taking off the sublimation tube, and then under the protection of argon the solid in the sublimation tube was shifted to another sealed tube ready for use.

Example A2 Preparation of lanthanum acetylacetonate $\text{La}(\text{acac})_3$ (cf.

Polymer, 2001, 42, 7511-7516)

In a 250 ml three-neck flask, $\text{LaCl}_3 \cdot 7\text{H}_2\text{O}$ (3.47 g, 9.37 mmol) was dissolved with 50 ml water to obtain a solution s1, said solution s1 being dropwise fed to a 50 ml aqueous solution s2 of acetylacetone (5.63 g, 56.2 mmol). The solution as mixed was stirred at room temperature, and 2 N KOH was added to it until the solution had a pH of 7. The reaction mixture containing a precipitate of $\text{La}(\text{acac})_3$ was stirred and filtered. Then, about 4 g of $\text{La}(\text{acac})_3$ was obtained after drying in vacuum at 60°C.

Example A3 Preparation of RE isopropoxide (cf. Inorg. Chem., 1970, 9(1), 2505-2510)

In a 250 ml three-neck flask, 0.02 mol anhydrous RE chloride was dissolved with 80 ml isopropanol by refluxing under heating. The obtained solution was cooled down to room temperature, to which a solution of sodium isopropoxide (obtained by dissolving 1.349 g sodium with a mixture of 20 ml isopropanol and 65 ml benzene) was dropped with rapid stirring. After finishing the dropping, the solution was refluxed by heating for 4 h, and then cooled down followed by standing for overnight. The resulted solution was filtered with G4 sand-core filter bulb, the obtained filtrate was distilled to remove solvent, and then about 15 g of RE isopropoxide powder was obtained after drying under vacuum.

Example A4 Preparation of RE tri(2,6-di-tert-butyl-4-methylphenolate) (cf. Inorg. Chim. Acta, 1987, 139, 183-184)

0.5-0.8 g of anhydrous LnCl_3 was exactly weighted and added to a polymerization ampoule under the protection of argon. According to the molar weight of LnCl_3 , the demand of 2,6-di-tert-butyl-4-methylphenol was calculated based on a molar ratio of 1:3.

An exact amount of 2,6-di-tert-butyl-4-methylphenol was added to a flask having a branch tube (through the branch tube argon is charged) under the

protection of argon, to which 30 ml THF solvent was injected with stirring to obtain a solution. After adding excess sodium, the solution reacted at room temperature for 2-3 h until no bubble produced on the surface of the sodium. A little of sodium was continuously added to judge whether the reaction had been completed, thereby obtaining a THF solution of sodium 2,6-di-tert-butyl-4-methylphenolate.

The anhydrous LnCl_3 weighted was shifted to a 50 ml single-neck reaction bottle followed by the THF solution of sodium 2,6-di-tert-butyl-4-methylphenolate, to which argon was thoroughly filled. The system reacted in an oil bath of 80-90°C by magnetic stirring for 2-3 days. The reaction product obtained is centrifugally filtered, and the filtrate is distilled under vacuum to remove solvent. Then, the desired RE tri(2,6-di-tert-butyl-4-methylphenolate) catalyst was obtained after drying for 1 h under vacuum.

Example A5 Preparation of RE stearate

A calculated amount of Ln_2O_3 was weighted with a beaker, to which a suitable amount of distilled water was added followed by excess amount of HCl, and then the system was heated to dissolve thereby obtaining a transparent solution s3. Excess stearic acid was weighed with another beaker, to which a suitable amount of anhydrous ethanol was added to obtain a transparent solution s4 when heated. The solutions s4 and s3 were added in sequence to a 100 ml round flask, to which 10 mg a phase transfer catalyst tetrabutylammonium bromide was charged followed by a magnet stirrer. A condensation tube was connected above the flask under the protection of nitrogen atmosphere. The system was heated in an oil bath of less than 100°C by magnetic stirring for about 5 h. The lower clear liquor was separated with a separatory funnel, and further evaporated to dryness.

Example A6 Preparation of RE acetate (cf. J. Inorg. Nucl. Chem., 1962, 24, 637-639)

10 g of a RE oxide was dissolved with 500 ml 50% acetic acid solution. After removing most of the solvent by distilling at 75°C, the RE salt obtained was heated to 75-150°C (depending on different RE) under vacuum, and then dried till constant weight, thereby obtaining the corresponding RE acetate.

Comparative Example A1 Preparation of a polyester with single-component Ti catalyst

136 g (0.7 mol) dimethyl terephthalate, 126 g (1.4 mol) butanediol and 0.20 g (0.59 mmol) tetrabutyl orthotitanate were added to a 500 ml three-neck flask. Under the protection of nitrogen, the system was heated with stirring till refluxing. By controlling the reaction temperature at 160-220°C, methanol evaporated was collected. After finishing the collection of methanol, the system was vacuum supplied and heated, and then underwent polycondensation at a vacuum pressure of ≤ 200 Pa and a temperature of 220-260°C for 10 h. The obtained product had a yellow color and a viscosity number (VN) of 67 ml/g.

Comparative Example A2 Preparation of a copolyester with a single-component Ti catalyst

78 g (0.4 mol) dimethyl terephthalate, 86.5 g (0.96 mol) butanediol and 0.17 g (0.5 mmol) tetrabutyl orthotitanate were added to a 500 ml three-neck flask. Under the protection of nitrogen, the system was heated with stirring till refluxing. By controlling the reaction temperature at 160-220°C, methanol evaporated was collected. After finishing the collection of methanol, 58.5 g (0.4 mol) adipic acid was added to the system, and the system was continuously heated with stirring till refluxing. By controlling the reaction temperature at 180-240°C, water evaporated was collected. After finishing the collection of water, the system was vacuum supplied and heated, and then underwent

polycondensation at a vacuum pressure of ≤ 200 Pa and a temperature of 220-260°C for 10 h. The obtained product was yellow, and had a number-average molecular weight M_n of 2.68×10^4 , a weight-average molecular weight M_w of 5.29×10^4 , and a molecular weight distribution of 1.97 (as determined by GPC).

Comparative Example A3

78 g (0.4 mol) dimethyl terephthalate, 86.5 g (0.96 mol) butanediol, 0.11 g (0.32 mmol) tetrabutyl orthotitanate and 0.073g(0.17mmol) lanthanum acetylacetonate were added to a 500 ml three-neck flask. Under the protection of nitrogen, the system was heated with stirring till refluxing. By controlling the reaction temperature at 160-220°C, methanol evaporated was collected. After finishing the collection of methanol, 58.5 g (0.4 mol) adipic acid was added to the system, and the system was continuously heated with stirring till refluxing. By controlling the reaction temperature at 180-240°C, water evaporated was collected. After finishing the collection of water, the system was vacuum supplied and heated, and then underwent polycondensation at a vacuum pressure of ≤ 200 Pa and a temperature of 220-260°C for 7 h. The obtained product was light yellow, and had a number-average molecular weight M_n of 3.08×10^4 , a weight-average molecular weight M_w of 6.21×10^4 , and a molecular weight distribution of 2.02 (as determined by GPC).

Comparative Example A4

78 g (0.4 mol) dimethyl terephthalate, 86.5 g (0.96 mol) butanediol and 0.11 g (0.32 mmol) tetrabutyl orthotitanate were added to a 500 ml three-neck flask. Under the protection of nitrogen, the system was heated with stirring till refluxing. By controlling the reaction temperature at 160-220°C, methanol evaporated was collected. After finishing the collection of methanol, 58.5 g (0.4 mol) adipic acid was added to the system, and the system was continuously

heated with stirring till refluxing. By controlling the reaction temperature at 180-240°C, water evaporated was collected, and then 0.073 g (0.17 mmol) lanthanum acetylacetonate was added to the system after finishing the collection of water. Afterward, the system was vacuum supplied and heated, and then underwent polycondensation at a vacuum pressure of ≤ 200 Pa and a temperature of 220-260°C for 7 h. The obtained product was white, and had a number-average molecular weight M_n of 3.84×10^4 , a weight-average molecular weight M_w of 8.88×10^4 , and a molecular weight distribution of 2.31 (as determined by GPC).

Example A7

136 g (0.7 mol) dimethyl terephthalate, 126 g (1.4 mol) butanediol and 0.10 g (0.29 mmol) tetrabutyl orthotitanate were added to a 500 ml three-neck flask. Under the protection of nitrogen, the system was heated with stirring till refluxing. By controlling the reaction temperature at 160-220°C, methanol evaporated was collected. After finishing the collection of methanol, the system was vacuum supplied, heated, and reacted at a vacuum pressure of 400 Pa and a temperature of 220-260°C for about 1 h. Thereafter, 0.073 g (0.17 mmol) lanthanum acetylacetonate was added to the system, followed by allowing the system to polycondense at a vacuum pressure ≤ 200 Pa and a temperature of 220-260°C for 5 h. The obtained product had a white color and a viscosity number (VN) of 141 ml/g.

Example A8

78 g (0.4 mol) dimethyl terephthalate, 86.5 g (0.96 mol) butanediol and 0.11 g (0.32 mmol) tetrabutyl orthotitanate were added to a 500 ml three-neck flask. Under the protection of nitrogen, the system was heated with stirring till refluxing. By controlling the reaction temperature at 160-220°C, methanol evaporated was collected. After finishing the collection of methanol, 58.5 g (0.4

mol) adipic acid was added to the system, and the system was continuously heated with stirring till refluxing. By controlling the reaction temperature at 180-240°C, water evaporated was collected. After finishing the collection of water, the system was vacuum supplied, heated, and reacted at a vacuum pressure of 400 Pa and a temperature of 220-260°C for about 1 h. Afterward, 0.073 g (0.17 mmol) lanthanum acetylacetonate was added to the system, followed by allowing the system to polycondense at a vacuum pressure ≤ 200 Pa and a temperature of 220-260°C for 6 h. The obtained product was white, and had a number-average molecular weight M_n of 4.53×10^4 , a weight-average molecular weight M_w of 1.02×10^5 , and a molecular weight distribution of 2.25 (as determined by GPC).

Example A9

The process conditions were the same as those in Example A8 except that 0.055 g (0.17 mmol) neodymium isopropoxide was used instead of lanthanum acetylacetonate.

Example A10

The process conditions were the same as those in Example A8 except that 0.14 g (0.17 mmol) lanthanum tri(2,6-di-tert-butyl-4-methylphenolate) was used instead of lanthanum acetylacetonate.

The parameters characterizing the copolyesters respectively obtained in Comparative Examples A1-A4 and in Examples A7-A10 are listed in Table A1 and Table A2.

Table A1 Influence of the addition of RE compound on the preparation of polyester

No.	RE compound	Polycondensation time (h)	Viscosity number VN (ml/g)	Yellow index
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Comparative Example A1	Not added	10	67	61.2
Example A7	Added	5	141	41.5

Table A2 Influence of the addition manner of RE compound on the polymerization of copolyester

No.	Addition manner of RE compounds	Polycondensation time (h)	Molecular weight			Yellow index
			M _n	M _w	M _w /M _n	
Comparative Example A2	Non-added	10	2.68	5.29	1.97	75.5
Comparative Example A3	Added along with Cat1	7	3.08	6.21	2.02	58.1
Comparative Example A4	Added after interesterification and before polycondensation	7	3.84	8.88	2.31	49.5
Example A8	Added after prepolymerization and before polycondensation	6	4.53	10.2	2.25	47.9
Example A9	Added after prepolymerization and before polycondensation	6	8.12	16.3	2.01	40.1
Example A10	Added after prepolymerization and before polycondensation	6	7.76	15.3	1.97	41.2

Examples B6-B11

Taking as example the preparation of copolyesters having an aliphatic/aromatic molar ratio of 1:1 (DMT/ADP being 1:1). In the catalyst system, Cat1 uses tetrabutyl orthotitanate or zinc acetate; and Cat2 uses different RE compounds.

78 g (0.4 mol) dimethyl terephthalate DMT, 86.5 g (0.96 mol) butanediol BD and a Cat1 component (which may not be added) were added to a 500 ml three-neck flask. Under the protection of nitrogen, the system was heated with

stirring till refluxing. By controlling the reaction temperature at 160-220°C, methanol evaporated was collected. After finishing the collection of methanol, 58.5 g (0.4 mol) adipic acid ADP was added to the system, and the system was continuously heated with stirring till refluxing. By controlling the reaction temperature at 180-240°C, water evaporated was collected. After finishing the collection of water, the system was vacuum supplied, heated, and reacted at a vacuum pressure of 400 Pa and a temperature of 220-260°C for about 1 h. Afterward, 0.17 mmol of a Cat2 component was added to the system, followed by allowing the system to polycondense at a vacuum pressure of ≤ 200 Pa and a temperature of 220-260°C for 7 h. The catalyst components Cat1 and Cat2 used as well as the performances of the copolyester products obtained are listed in Table B1.

Table B1 Performances of copolyesters prepared by different catalyst systems

No.	Cat1/Cat2	Yellow index	Molecular weight		
			M_n ($\times 10^4$)	M_w ($\times 10^4$)	M_w/M_n
Example B6	0.11 g tetrabutyl orthotitanate/0.073 g lanthanum acetylacetonate	37.2	6.82	14.0	2.05
Example B7	0.11 g tetrabutyl orthotitanate/0.063 g lanthanum chloride hydrate	39.5	4.98	10.9	2.18
Example B8	0.5 g zinc acetate/0.055 g neodymium isopropoxide	3.8	46.1	57.6	1.25
Example B9	0.5 g zinc acetate/0.13 g neodymium tri(2,6-di-tert-butyl-4-methylphenolate)	5.4	30.8	55.7	1.81
Example B10	0/scandium stearate	11.7	8.24	13.4	1.63
Example B11	0/yttrium acetate	6.5	5.95	11.8	1.99

Example B12

78 g (0.4 mol) dimethyl terephthalate DMT, 86.5 g (0.96 mol) butanediol BD and 0.11 g (0.32 mmol) tetrabutyl orthotitanate were added to a 500 ml three-neck flask. Under the protection of nitrogen, the system was heated with

stirring till refluxing. By controlling the reaction temperature at 160-220°C, methanol evaporated was collected. After finishing the collection of methanol, 47.2 g (0.4 mol) succinic acid SCN was added to the system, and the system was continuously heated with stirring till refluxing. By controlling the reaction temperature at 180-240°C, water evaporated was collected. After finishing the collection of water, the system was vacuum supplied, heated and reacted at a vacuum pressure of 400 Pa and a temperature of 220-260°C for 1 h. Afterward, 0.055 g (0.17 mmol) neodymium isopropoxide was added to the system, followed by allowing the system to polycondense at a vacuum pressure of ≤ 200 Pa and a temperature of 220-260°C for 7 h. The obtained product was white, and had a number-average molecular weight M_n of 5.41×10^4 , a weight-average molecular weight M_w of 1.11×10^5 , and a molecular weight distribution of 2.05 (as determined by GPC).

Examples B13-B23

Homo- and co-polyesters having different aliphatic/aromatic molar ratios are prepared by using a catalyst system consisting of Cat2 lanthanum acetylacetonate and Cat1 tetrabutyl orthotitanate (1:1).

Example B13

136 g (0.7 mol) dimethyl terephthalate, 126 g (1.4 mol) butanediol and 0.10 g (0.3 mmol) tetrabutyl orthotitanate were added to a 500 ml three-neck flask. Under the protection of nitrogen, the system was heated with stirring till refluxing. By controlling the reaction temperature at 160-220°C, methanol evaporated was collected. After finishing the collection of methanol, the system was vacuum supplied, heated, and reacted at a vacuum pressure of 400 Pa and a temperature of 220-260°C for about 1 h. Afterward, 0.13 g (0.3 mmol) lanthanum acetylacetonate was added to the system, followed by allowing the system to polycondense at a vacuum pressure of ≤ 200 Pa and a temperature of

220-260°C for 4 h.

Example B14

155 g (0.8 mol) dimethyl terephthalate, 120 g (1.34 mol) butanediol and 0.13 g (0.37 mmol) tetrabutyl orthotitanate were added to a 500 ml three-neck flask. Under the protection of nitrogen, the system was heated with stirring till refluxing. By controlling the reaction temperature at 160-220°C, methanol evaporated was collected. After finishing the collection of methanol, 13.0 g (0.089 mmol) adipic acid was added to the system, and the system was continuously heated with stirring till refluxing. By controlling the reaction temperature at 180-240°C, water evaporated was collected. After finishing the collection of water, the system was vacuum supplied, heated, and reacted at a vacuum pressure of 400 Pa and a temperature of 220-260°C for about 1 h. Afterward, 0.16 g (0.37 mmol) lanthanum acetylacetonate was added to the system, followed by allowing the system to polycondense at a vacuum pressure of ≤ 200 Pa and a temperature of 220-260°C for 4 h.

Example B15

The process conditions were identical with those in Example B14 except that the amounts of the monomers and the catalyst components were changed as follows: 117 g (0.6 mol) dimethyl terephthalate, 86.5 g (0.96 mol) butanediol, 0.09 g (0.26 mmol) tetrabutyl orthotitanate, 29.0 (0.2 mol) adipic acid, and 0.116 g (0.26 mmol) lanthanum acetylacetonate.

Example B16

The process conditions were identical with those in Example B14 except that the amounts of the monomers and the catalyst components were changed as follows: 87.0 g (0.45 mol) dimethyl terephthalate, 108 g (1.2 mol) butanediol, 0.11 g (0.32 mmol) tetrabutyl orthotitanate, 44.0 (0.3 mol) adipic acid, and 0.14

g (0.32 mmol) lanthanum acetylacetonate.

Example B17

The process conditions were identical with those in Example B14 except that the amounts of the monomers and the catalyst components were changed as follows: 78 g (0.4 mol) dimethyl terephthalate, 86.5 g (0.96 mol) butanediol, 0.12 g (0.34 mmol) tetrabutyl orthotitanate, 58.5 (0.4 mol) adipic acid, and 0.15 g (0.34 mmol) lanthanum acetylacetonate.

Example B18

The process conditions were identical with those in Example B14 except that the amounts of the monomers and the catalyst components were changed as follows: 58.0 g (0.3 mol) dimethyl terephthalate, 81 g (0.9 mol) butanediol, 0.11 g (0.32 mmol) tetrabutyl orthotitanate, 66.0 (0.45 mol) adipic acid, and 0.14 g (0.32 mmol) lanthanum acetylacetonate.

Example B19

The process conditions were identical with those in Example B14 except that the amounts of the monomers and the catalyst components were changed as follows: 58.0 g (0.3 mol) dimethyl terephthalate, 108 g (1.2 mol) butanediol, 0.10 g (0.3 mmol) tetrabutyl orthotitanate, 88.0 (0.6 mol) adipic acid, and 0.13 g (0.3 mmol) lanthanum acetylacetonate.

Example B20

The process conditions were identical with those in Example B14 except that the amounts of the monomers and the catalyst components were changed as follows: 58.0 g (0.3 mol) dimethyl terephthalate, 122 g (1.35 mol) butanediol, 0.12 g (0.35 mmol) tetrabutyl orthotitanate, 110.0 (0.75 mol) adipic acid, and 0.15 g (0.35 mmol) lanthanum acetylacetonate.

Example B21

The process conditions were identical with those in Example B14 except that the amounts of the monomers and the catalyst components were changed as follows: 39.0 g (0.2 mol) dimethyl terephthalate, 108 g (1.2 mol) butanediol, 0.09 g (0.26 mmol) tetrabutyl orthotitanate, 88.0 (0.6 mol) adipic acid, and 0.12 g (0.26 mmol) lanthanum acetylacetonate.

Example B22

The process conditions were identical with those in Example B14 except that the amounts of the monomers and the catalyst components were changed as follows: 26.1 g (0.13 mol) dimethyl terephthalate, 108 g (1.2 mol) butanediol, 0.11 g (0.33 mmol) tetrabutyl orthotitanate, 132 (0.9 mol) adipic acid, and 0.15 g (0.33 mmol) lanthanum acetylacetonate.

Example B23

The process conditions were identical with those in Example B14 except that the amounts of the monomers and the catalyst components were changed as follows: 146 g (0.75 mol) dimethyl terephthalate, 108 g (1.2 mol) butanediol, 0.11 g (0.33 mmol) tetrabutyl orthotitanate, and 0.15 g (0.33 mmol) lanthanum acetylacetonate.

The copolyesters obtained in Examples B13-23 are analyzed, with the results being listed in Table B2.

Table B2 Preparation and performance parameters of copolyesters having different compositional ratios

No.	Molar feed ratio of monomers (DMT/ADP)	Molar ratio of monomers to catalysts	Molar ratio of monomers acid/dibasic alcohol (DMT+ADP)/BD	Compositional molar ratio of polymer (DMT/ADP)	Molecular weight		
					M _n (x10 ⁴)	M _w (x10 ⁴)	M _w /M _n
Example B13	100/0	1170	1/2	100/0	n.d. ^c	n.d.	n.d.
Example B14	90/10	1200	1/1.5	90/10	n.d.	n.d.	n.d.
Example B15	75/25	1500	1/1.2	75/25	n.d.	n.d.	n.d.
Example B16	60/40	1172	1/1.2	60/40	n.d.	n.d.	n.d.
Example B17	50/50	1172	1/1.2	50/50	6.20	12.6	2.03
Example B18	40/60	1172	1/1.2	40/60	6.15	11.6	1.88
Example B19	33/67	1500	1/1.3	35/65	6.08	13.6	2.23
Example B20	29/71	1500	1/1.3	30/70	6.21	13.2	2.12
Example B21	25/75	1540	1/1.5	25/75	6.31	11.9	1.89
Example B22	13/87	1560	1/1.2	13/87	6.50	13.4	2.06
Example B23	0/100	1140	1/1.6	0/100	6.48	12.0	1.85

^cn.d.: since the sample cannot be completely dissolved in THF solvent, its molecular weight and molecular weight distribution are not detected.

Example C1

87.0 g (0.45 mol) dimethyl terephthalate, 108 g (1.2 mol) butanediol and 0.11 g (0.32 mmol) tetrabutyl orthotitanate were added to a 500 ml three-neck

flask. Under the protection of nitrogen, the system was heated with stirring till refluxing. By controlling the reaction temperature at 160-220°C, methanol evaporated was collected. After finishing the collection of methanol, 13.0 g (0.089 mmol) adipic acid was added to the system, and the system was continuously heated with stirring till refluxing. By controlling the reaction temperature at 180-240°C, water evaporated was collected. After finishing the collection of water, the system was vacuum supplied, heated, and reacted at a vacuum pressure of 400 Pa and a temperature of 220-260°C for about 1 h. Afterward, 0.10 g (0.32 mmol) lanthanum isopropoxide was added to the system, followed by allowing the system to polycondense at a vacuum pressure of ≤ 200 Pa and a temperature of 220-260°C for 7 h.

Example C2

The process conditions were identical with those in Example C1 except that the amounts of the monomers and the catalyst components were changed as follows: 78 g (0.4 mol) dimethyl terephthalate, 86.5 g (0.96 mol) butanediol, 0.12 g (0.34 mmol) tetrabutyl orthotitanate, 58.5 (0.4 mol) adipic acid, and 0.11 g (0.35 mmol) lanthanum isopropoxide.

Example C3

The process conditions were identical with those in Example C1 except that the amounts of the monomers and the catalyst components were changed as follows: 58.0 g (0.3 mol) dimethyl terephthalate, 81 g (0.9 mol) butanediol, 0.11g (0.32 mmol) tetrabutyl orthotitanate, 66.0 (0.45 mol) adipic acid, and 0.10 g (0.32 mmol) lanthanum isopropoxide.

Example C4

The process conditions were identical with those in Example C1 except that the amounts of the monomers and the catalyst components were changed as

follows: 58.0 g (0.3 mol) dimethyl terephthalate, 108 g (1.2 mol) butanediol, 0.10 g (0.3 mmol) tetrabutyl orthotitanate, 88.0 (0.6 mol) adipic acid, and 0.09 g (0.3 mmol) lanthanum isopropoxide.

Example C5

The process conditions were identical with those in Example C1 except that the amounts of the monomers and the catalyst components were changed as follows: 58.0 g (0.3 mol) dimethyl terephthalate, 122 g (1.35 mol) butanediol, 0.12 g (0.35 mmol) tetrabutyl orthotitanate, 110.0 g (0.75 mol) adipic acid, and 0.11 g (0.35 mmol) lanthanum isopropoxide.

Example C6

The process conditions were identical with those in Example C1 except that the amounts of the monomers and the catalyst components were changed as follows: 39.0 g (0.2 mol) dimethyl terephthalate, 108 g (1.2 mol) butanediol, 0.09 g (0.26 mmol) tetrabutyl orthotitanate, 88.0 (0.6 mol) adipic acid, and 0.08 g (0.26 mmol) lanthanum isopropoxide.

The copolyesters obtained in Examples C1-C6 are analyzed, with the results being listed in Table C1.

Table C1 Preparation and performance parameters of the copolyesters having different compositional ratios

No.	Molar feed ratio of monomers (DMT/ADP)	Compositiona 1 molar ratio of polymer (BT/BA) ^a	Molecular weight			T _g (°C)	T _m (°C)	Tensile		Time for complete degradation (day)
			M _n (×10 ⁴)	M _w (×10 ⁴)	M _w /M _n			Strength (MPa)	Strain (%)	
Example C1	60/40	60/40	n.d. ^b	n.d.	n.d.	-18.5	154.2	33.2	688	240
Example C2	50/50	50/50	7.18	15.6	2.17	-28.3	129.5	28.7	874	120
Example C3	40/60	40/60	6.73	15.0	2.23	-37.0	106.7	23.8	940	30
Example C4	33/67	35/65	7.31	17.7	2.42	-40.1	40.8	13.6	972	25
Example C5	29/71	30/70	6.72	16.2	2.41	-47.1	20.3	10.6	1204	15
Example C6	25/75	25/75	8.15	15.7	1.93	-46.0	42.7	10.5	1100	15

^a: BT is aromatic chain segment, and BA is aliphatic chain segment.

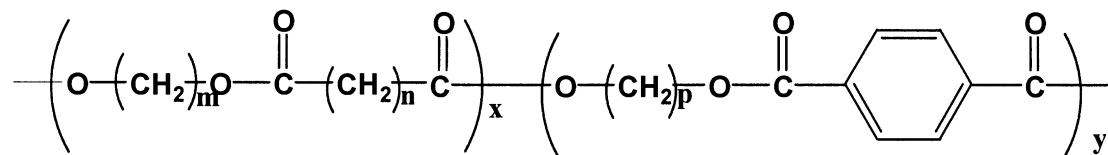
^bn.d.: since the sample cannot be completely dissolved in THF solvent, its molecular weight and molecular weight distribution are not detected.

T_g indicates glass temperature. T_m indicates melting temperature.

By characterizing the polymer's structure with ¹H NMR, it is found that, taking Example C2 (DMT/ADP = 1/1) as an example, as shown in Fig. 1 in combination with the single peak character in GPC and the sole melting peak in DSC, the copolyester is a typical random copolymer and conforms to statistical distribution law.

Claims

1. A random linear aliphatic/aromatic copolyester, which comprises the following structural unit:



wherein m is an integer of 2 to 10, n is an integer of 0 to 8, p is an integer of 2 to 10, m, n and p being same or different, x is an integer of 1 to 10, and y is an integer of 1 to 10; and

wherein the copolyester has a weight-average molecular weight M_w of 100,000-600,000 g/mol, and a molecular weight distribution of 1.2-3, as determined by GPC.

2. The copolyester according to claim 1, wherein m is an integer of 2 to 4, n is an integer of 2 to 4, p is an integer of 2 to 4, x is an integer of 1 to 3, and/or y is an integer of 1 to 2.

3. The copolyester according to claim 1, which has a weight-average molecular weight M_w of 100,000-300,000 g/mol, and a molecular weight distribution of 1.5-2.5.

4. The copolyester according to claim 1, which has a melting temperature range of 20 to 185°C.

5. The copolyester according to claim 1, which has a glass temperature of -55 to -7°C.

6. Use of the copolyester according to any one of claims 1-5 in profiles,

films, fibers or coatings.

7. A process for synthesizing a polyester, comprising the steps of:

1) adding the following monomers and an optional catalyst component Cat1 to a reactor to carry out interesterification and/or esterification: (a) aromatic dicarboxylic acid, ester thereof, anhydride thereof, or mixture thereof, (b) aliphatic diol, alicyclic diol or mixture thereof, and (c) aliphatic dicarboxylic acid, alicyclic dicarboxylic acid, ester thereof, anhydrides thereof, or mixture thereof,

wherein the molar ratio of the monomer (a)/monomer (c) is 0:100-100:0;

2) prepolymerizing the reaction system obtained in step 1) under vacuum; and

3) adding a catalyst component Cat2 to the prepolymerized product obtained in step 2) to carry out polycondensation under vacuum, thereby obtaining the desired polyester;

wherein, the catalyst component Cat1 is selected from the group consisting of the compounds of Ti, Sb and Zn, and mixtures thereof;

the catalyst component Cat2 is selected from the group consisting of the compounds of RE Ln and mixtures thereof, said RE Ln being selected from the group consisting of La-series elements, Sc and Y and combinations thereof.

8. The process according to claim 7, wherein a catalyst component Cat2 is added after the temperature of fraction is kept constant in the reaction system of step 2).

9. The process according to claim 7, wherein, in the step 1), the catalyst component Cat1, and the monomers (a) and (b) firstly react by adding them to a reactor, followed by reacting with the monomer (c) to be added.

10. The process according to claim 7, wherein the molar ratio of the monomer (a)/monomer (c) is 0:100-65:35; the molar ratio of the monomers (a)+(c)/monomer (b) is 1:(1.0-3.0); and the molar ratio of the catalyst system/the monomers (a)+(c) is 1:(500-10,000).

11. The process according to claim 10, wherein the molar ratio of the monomer (a)/monomer (c) is 35:65-60:40.

12. The process according to claim 10, wherein the molar ratio of the monomers (a)+(c)/monomer (b) is 1:(1.1-1.5), and the molar ratio of the catalyst system/the monomers (a)+(c) is 1:(1,000-3,000).

13. The process according to claim 12, wherein the molar ratio of the monomers (a)+(c)/monomer (b) is 1:(1.2-1.4).

14. The process according to claim 7, wherein the monomer (a) is selected from the group consisting of p-phenylene dicarboxylic acid, ester thereof, anhydride thereof, or mixtures thereof; the monomer (b) is selected from the group consisting of C₂-C₆ aliphatic diol, C₅-C₁₀ alicyclic diol or mixtures thereof; and the monomer (c) is selected from the group consisting of C₃-C₁₀ aliphatic dicarboxylic acid, C₅-C₁₀ alicyclic dicarboxylic acid, ester thereof, anhydrides thereof or mixtures thereof.

15. The process according to claim 14, wherein the monomer (a) is terephthalic acid or dimethyl terephthalate; the monomer (b) is 1,4-butanediol, 1,3-propanediol or ethylene glycol; and the monomer (c) is adipic acid, sebacic acid or succinic acid.

16. The process according to claim 7, wherein the monomer (a) is selected

from the group consisting of terephthalic acid, ester thereof, anhydride thereof or mixtures thereof; the monomer (b) is selected from the group consisting of C₂-C₆ aliphatic diol, C₅-C₁₀ alicyclic diol or mixtures thereof; and the monomer (c) is selected from the group consisting of adipic acid, ester thereof, anhydride thereof or mixtures thereof.

17. The process according to claim 16, wherein the molar ratio of the monomer (a)/monomer (c) is (5-75):(25-95), and the molar ratio of the monomers (a)+(c)/monomer (b) is 1:1-1:2.

18. The process according to claim 17, wherein the molar ratio of the monomer (a)/monomer (c) is (25-65):(35-75), and the molar ratio of the monomers (a)+(c)/monomer (b) is 1:1.2-1:1.5.

19. The process according to claim 7, wherein the catalyst component Cat 1 is selected from the group consisting of M(OR₂')_x, M₂O_x, M(R₁'COO)_x and mixtures thereof,

the catalyst component Cat2 is selected from the group consisting of RE metal's inorganic halides LnX₃, carboxylates Ln(R₁COO)₃, alkoxides Ln(OR₂)₃, aryloxides Ln(OAr)₃, acetylacetonates Ln(a_ca_c)₃, hydrates thereof and mixtures thereof,

and, the molar ratio of Cat2/Cat1 is 5:95-100:0;

in which, X is a halogen ion, a_ca_c is an acetylacetone group,

R₁ and R₁' are selected from C₁-C₃ alkyl, R₁, R₁' being same or different,

R₂ and R₂' are selected from C₃-C₆ alkyl, R₂, R₂' being same or different,;

Ar is selected from C₁-C₄ alkyl substituted phenyl, and

M is metal Ti, Sb or Zn, and x is 2, 3 or 4.

20. The process according to claim 19, wherein the RE Ln is selected from

the group consisting of La, Ce, Pr, Nd, Td, Yb, Dy, Sm, Sc and combinations thereof.

21. The process according to claim 20, wherein the RE Ln is selected from the group consisting of La, Ce, Pr, Nd, Sc and combinations thereof.

22. The process according to claim 19, wherein the catalyst component Cat 1 is selected from the group consisting of titanium alkoxide $Ti(OR_2')_x$, antimony acetate, zinc acetate, zinc oxides, antimony oxides, titanium oxides, mixtures thereof,

the catalyst component Cat2 is selected from the group consisting of RE inorganic halides LnX_3 , alkoxides $Ln(OR_2)_3$, aryloxides $Ln(OAr)_3$, acetylacetonates $Ln(a_c a_c)_3$ excluding samarium acetylacetonate $Sm(a_c a_c)_3$, and mixtures thereof,

wherein, X is chlorine ion or bromine ion, R_2 is isopropyl, n-butyl or isopentyl, Ar is 2,6-di-tert-butyl-4-methylphenyl or 4-butylphenyl;

and, the molar ratio of Cat2/Cat1 is 1:3-3:1:

23. The process according to claim 22, wherein the Cat 1 is tetrabutyl orthotitanate, titanium isopropoxide, titanium dioxide, antimony trioxide, antimony acetate or zinc acetate,

and the molar ratio of Cat2/Cat1 is 2:3-3:2:

24. The process according to claim 7, wherein the catalyst component Cat1 is selected from the group consisting of tetrabutyl orthotitanate, titanium isopropoxide, titanium dioxide, antimony trioxide, antimony acetate, zinc acetate and mixtures thereof,

the catalyst component Cat2 is selected from the group consisting of RE inorganic halides LnX_3 , carboxylates $Ln(R_1COO)_3$, alkoxides $Ln(OR_2)_3$,

aryloxides $\text{Ln}(\text{OAr})_3$, and mixtures thereof,

and, the molar ratio of Cat2/Cat1 is 2:3-3:2;

in which, the RE Ln is selected from the group consisting of La, Ce, Pr, Nd, Sc and combinations thereof,

X is chlorine ion or bromine ion,

R_1 is ethyl or propyl, R_2 is isopropyl, b-butyl or isopentyl, and

Ar is 2,6-di-tert-butyl-4-methylphenyl or 4-butylphenyl.

25. The process according to claim 7, wherein the steps 1), 2) and 3) are carried out in the same autoclave.

26. The process according to claim 7, wherein no chain extender is added in any of the steps 1), 2) and 3).