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(54) Title: PHOTOOXIDATION TREATMENT OF POST-CONSUMER RECYCLATE

(57) Abstract: A method for recycling plastic waste including the step of photooxidizing plastic waste, wherein the plastic waste is selected from the group consisting of post-consumer recyclate and post-industrial recyclate and the photooxidizing step is selected from the group consisting of ultraviolet photooxidizing, visible-light photooxidizing, near-infrared photooxidizing, and oxygen-derived plasma treating.



PHOTOOXIDATION TREATMENT OF POST-CONSUMER RECYCLATE

FIELD OF THE INVENTION

[0001] In general, the present disclosure relates to the field of chemistry. More specifically, the present disclosure relates to post-consumer recyclate. In particular, the present disclosure relates to photooxidation of post-consumer recyclate, related processes, and products prepared therefrom.

BACKGROUND OF THE INVENTION

[0002] The downside to the demand for polyolefin plastics is an increase in plastic waste. As such, there is considerable interest in developing methods to recycle plastic waste. In addition to reducing the amount of plastic waste, other benefits of recycling plastic waste include reducing carbon footprint, consuming less energy, improving water consumption, and using less raw materials.

[0003] In many instances, before plastic waste is recycled and turned into usable resin, the plastic materials are gathered and sent through a process to produce plastic resin pellets. In some instances, the plastics recycling system is a mechanical recycling system, including the steps of sorting, cleaning, shredding, melting, and remolding.

[0004] In some instances, the resulting plastic resin pellets are made from or containing polyolefins, non-polyolefinic polymers, and other contaminants. In some instances, the non-polyolefinic polymers or the other contaminants are present in an amount that adversely affects the properties of the plastic resin pellets. In some instances, the non-polyolefinic polymers or the other contaminants provide stress points in articles made from or containing the plastic resin pellets.

BRIEF SUMMARY OF THE INVENTION

[0005] In a general embodiment, the present disclosure provides a method for recycling plastic waste including the step of photooxidizing plastic waste, wherein the plastic waste is selected from the group consisting of post-consumer recyclate and post-industrial recyclate. In some embodiments, the step of photooxidizing is selected from the group consisting of ultraviolet photooxidizing, visible-light photooxidizing, near-infrared photooxidizing, and oxygen-derived plasma treating.

[0006] In some embodiments, the present disclosure provides a post-consumer recycled resin prepared from a post-consumer recyclate, wherein the resin is selected from the group

consisting of polyethylene and polypropylene. In some embodiments, the polyethylene is a high-density polyethylene.

[0007] In some embodiments, the present disclosure provides a post-industrial recycled resin prepared from a post-industrial recyclate, wherein the resin is selected from the group consisting of polyethylene and polypropylene. In some embodiments, the polyethylene is a high-density polyethylene.

[0008] In some embodiments, the present disclosure provides a polymer composition made from or containing resin selected from the group consisting of a post-consumer recycled resin and a post-industrial recycled resin.

[0009] In some embodiments, the present disclosure provides an article of manufacture made from or containing a resin selected from the group consisting of post-consumer recycled resins and post-industrial recycled resins.

[0010] While multiple embodiments are disclosed, still other embodiments will become apparent to those skilled in the art from the following detailed description. As will be apparent, certain embodiments, as disclosed herein, are capable of modifications in various aspects, without departing from the spirit and scope of the claims as presented herein. Accordingly, the drawings and detailed description are to be regarded as illustrative in nature and not restrictive.

DETAILED DESCRIPTION OF THE INVENTION

[0011] While the provided embodiments will be described more fully hereinafter, these embodiments are provided to satisfy applicable laws and regulations. As such, it will be apparent to those skilled in the art that the embodiments can incorporate changes and modifications without departing from the general scope. This disclosure is intended to include the modifications and alterations in so far as the modifications and alterations come within the scope of the appended claims or the equivalents thereof.

[0012] As used in this specification and the claims, the singular forms “a,” “an,” and “the” include plural referents unless the context dictates otherwise.

[0013] As used in this specification and the claims, the terms “comprising,” “containing,” or “including” mean that at least the named compound, element, material, particle, or method step is present in the composition, the article, or the method, but does not exclude the presence of other compounds, elements, materials, particles, or method steps even if the other such compounds, elements, materials, particles, or method steps have the same function as that which is named, unless expressly excluded in the claims. It is also to be understood that the mention of one or more

method steps does not preclude the presence of additional method steps before or after the combined recited steps or intervening method steps between those steps expressly identified.

[0014] Moreover, it is also to be understood that the lettering of process steps or ingredients is for identifying discrete activities or ingredients and the recited lettering can be arranged in any sequence, unless expressly indicated.

[0015] For the purpose of the present description and of the claims which follow, except where otherwise indicated, numbers expressing amounts, quantities, percentages, and so forth, are to be understood as being modified by the term “about”. Also, ranges include any combination of the maximum and minimum points disclosed and include any intermediate ranges therein, which may or may not be specifically enumerated herein.

[0016] Definitions

[0017] In the present description, the term “additive composition” refers to a composition made from or containing an additive.

[0018] In the present description, the term “ α -olefin” or “alpha-olefin” means an olefin of formula $\text{CH}_2=\text{CH}-\text{R}$, wherein R is a linear or branched alkyl containing from 1 to 10 carbon atoms. In some embodiments, the α -olefin is selected from the group consisting of propylene, 1-butene, 1-pentene, 1-hexene, 1-octene, and 1-decene.

[0019] In the present description, the terms “chop,” “comminute,” “grind,” “mill,” “powder,” “pulverize,” and “triturate” are used interchangeably and refer to dividing or reducing post-consumer polymer-containing waste or post-industrial polymer-containing waste mechanically into particles having dimensions smaller than 1 mm (or 1000 microns), alternatively smaller than 100 microns, alternatively smaller than 10 microns, alternatively smaller than 1 micron, alternatively in the range of 10 microns to 1000 microns, alternatively 10 microns to 100 microns. In some embodiments, the resulting particles have a surface area between $0.4 \text{ cm}^2/\text{gram}$ to $2000 \text{ cm}^2/\text{gram}$, alternatively between $100 \text{ cm}^2/\text{gram}$ to $2000 \text{ cm}^2/\text{gram}$.

[0020] In the present description, the term “contaminant” refers to any chemical substance present in a post-consumer recyclate (PCR), a post-industrial recyclate (PIR), a post-consumer recycled resin (PCR resin), or a post-industrial recycled resin (PIR resin), wherein the PCR, the PIR, the PCR resin, or the PIR resin is made from or containing a selected polymer and the presence of the chemical substance thereby renders the PCR, the PIR, the PCR resin, or the PIR resin compositionally different from the pure, selected polymer. In some embodiments, the contaminant is present in an amount ranging from parts per billion (ppb) to percentages, based upon the total weight of the PCR, the PIR, the PCR resin, or the PIR resin. In some embodiments,

a multiplicity of contaminants is present. In some embodiments, the contaminant is selected from the group consisting of acrylonitrile butadiene styrene (ABS), calcium carbonate, coffee grounds, diapers, dirt, fillers, food stuffs, glass, grass, labels, metals (including aluminum), nylon, other inorganics, other polymers, paper, plant stems, polycarbonates, polyethylene terephthalate (PET), processing additives, property-imparting additives, rubbers, and wood.

[0021] In the present description, the term “elastomer” refers to polymer compounds having rubber-like properties and crystallinity in the range of from about 0 percent to about 20 percent.

[0022] In the present description, the term “first” refers to the order in which a particular species is presented and does not necessarily indicate that a “second” species will be presented. For example, “first polymer composition” refers to the first of at least one polymer composition. The term does not reflect priority, importance, or significance in any other way. Similar terms used that can be used herein include “second,” “third,” “fourth,” etc.

[0023] In the present description, the term “homopolymer” refers to polymers derived from a single monomeric units. To the extent that a homopolymer is derived from more than one monomeric unit, the incorporation of additional monomeric units has no measurable effect on the polymer’s primary, secondary, or tertiary structure or no effect on the polymer’s physical or chemical properties. In other words, there is no measurable difference between a polymer, comprising 100 weight percent of a first monomeric unit, and a co-polymer including more than one monomeric unit.

[0024] In the present description, the term “near-infrared photooxidation” refers to the use of near-infrared radiation in an oxygen- or ozone-rich environment to oxidize a molecular structure, thereby at least partially decompose the molecular structure.

[0025] In the present description, the term “near-infrared spectrum” refers to the segment of the electromagnetic spectrum having wavelengths within the range of about 700 to about 25000 nm.

[0026] In the present description, the term “International Code Council (ICC) Certification” refers to products certified as using 100% post consumer resins.

[0027] In the present description, the term “interpolymer” means a polymer prepared by the polymerization of at least two types of monomers or comonomers. The term “interpolymer” includes copolymers, terpolymers, tetrapolymers, and the like. In some embodiments, the term “copolymer” refers to polymers prepared from two different types of monomers or comonomers. In some embodiments, the term “terpolymer” refers to polymers prepared from three different

types of monomers or comonomers. In some embodiments, the term “tetrapolymer” refers to polymers prepared from four different types of monomers or comonomers. In some embodiments, the term “copolymer” is used interchangeably with “interpolymer” and refers to polymers made from three or more different types of monomers or comonomers.

[0028] In the present description, the terms “monomer” and “comonomer” are used interchangeably. The terms refer to any compound with a polymerizable moiety that is added to a reactor to produce a polymer. In those instances wherein a polymer is described as made from or containing one or more monomers, for example, a polymer made from or containing propylene and ethylene, the polymer, of course, is made from or containing units derived from the monomers, for example, $\text{—CH}_2\text{—CH}_2\text{—}$, and not the monomer itself, for example, $\text{CH}_2=\text{CH}_2$.

[0029] In the present description, the term “PCR” refers interchangeably to Post-Consumer Recycled or Post-Consumer Recyclate, including polymers such as high-density polyethylene (HDPE) and polypropylene (PP), which are recycled and reprocessed into a resin for use in various applications.

[0030] In the present description, the term “photodegradable resin” refers to a resin that is degraded via ultraviolet photooxidation or ketone photolysis. In the case of ketone photolysis (via Norrish reaction), the ketones are formed by thermolysis or photolysis of hydroperoxides, are exposed to light, and then undergo chain scission.

[0031] In the present description, the term “photodegradation” refers to photolysis, ultraviolet photooxidation, or both, resulting from the exposure of a polymer to ultraviolet radiation. In some instances, the ultraviolet radiation produces free radicals. In some instances, the production of free radicals is followed by chain scission, crosslinking, secondary oxidation, or grafting. In some instances, the photodegradation occurs by direct oxidation. In the present description, the terms “photodegradation,” “degradation,” and “decomposition” are used interchangeably.

[0032] In the present description, the term “PIR” refers interchangeably to Post-Industrial Recycled or Post-Industrial Recyclate.

[0033] In the present description, the term “oxygen-derived plasma treatment” refers to the modification of polyolefins or contaminants via plasma treatment with oxygen used in the plasma generation. The interaction between the active species in plasma generation using oxygen and the polyolefins’ surface leads to the formation of free radicals at the surface of the polyolefins. Oxygens leads to a functional group containing-oxygen atom selected from the group consisting of hydroxyl groups, carbonyl groups, and carboxylic groups. In some embodiments, the non-

polyolefin polymeric contaminants are oxidized using plasma treatment with oxygen. In some embodiments, the oxidizing gas is selected from the group consisting of air, oxygen, nitrous oxide, and water.

[0034] In the present description, the term “polyamide” refers to a polymer bearing recurring amide groups in the polymer’s backbone. Polycaprolactam and poly(hexamethylene adipamide) are commercially-available polyamides, which are respectively designated as “nylon 6” and “nylon 66”. Other nylons include nylon 11, nylon 12, nylon 46, and nylon 612.

[0035] As polyamide fibers and polyamide thermoplastics, aliphatic polyamides are used in various applications. In some instances, polyamide fibers are prepared in a melt-spun process and used in apparel, carpets, home textiles, surgical sutures, tire reinforcement, and other applications.

[0036] In some instances, polyamide thermoplastics are prepared with processes blow molding, extrusion, injection molding, and other thermoplastic processing methods. Polyamide thermoplastics are used in automotive applications (including body panels, fenders, and head light housings), electrical applications (including connectors, plugs, sockets, and switches), packaging applications (including food containers as moisture and oxygen barriers), clothing, and toys. For some applications, polyamide thermoplastics are coextruded with other polymers.

[0037] It is believed that the amount of α,β -unsaturated carbonyls affect the rate of photooxidation of nylon 66. It is believed that the photooxidation of nylon yields imides, conjugated aldehydes, and other carbonyl species.

[0038] In the present description, the term “polymer” means a macromolecular compound prepared by polymerizing monomers of the same or different type. The term “polymer” includes homopolymers, copolymers, terpolymers, interpolymers, and so on.

[0039] In the present description, the term “polymer composition” refers to a composition made from or containing a polymer.

[0040] In the present description, the term “polyolefin” is used herein broadly to include polymers such as polyethylene, ethylene- α olefin copolymers (EAO), polypropylene, polybutene, and ethylene copolymers having at least about 50 percent by weight of ethylene polymerized with a lesser amount of a comonomer such as vinyl acetate, and other polymeric resins within the “olefin” family classification.

[0041] Polyolefins can be made by a variety of processes including batch and continuous processes using single, staged, or sequential reactors, slurry, solution, and fluidized bed processes

and one or more catalysts including for example, heterogeneous and homogeneous systems and Ziegler, Phillips, metallocene, single-site, and constrained geometry catalysts to produce polymers having different combinations of properties.

[0042] In the present description, the term “post consumer recycled (PCR) resin” refers to the recycled product of waste created by consumers, including high-density polyethylene post-consumer recycled resin (HDPE PCR) and polypropylene post-consumer recycled resin (PP PCR). Among other forms, PCR resins may take the form of granules, pellets, and powders.

[0043] In the present description, the term “post industrial recycled (PIR) resin” refers to the recycled product of waste generated by manufacturers during the preparation of polymer-based products. In the present description, the disclosed, recycling processes for preparing and using PCR resins are extendable to PIR resins.

[0044] In the present description, the term “recycle” refers to the conversion of waste into a reusable material. The waste is created by consumers, in the case of post-consumer waste, or by manufacturers during the preparation of polymer-based products, in the case of post-industrial waste.

[0045] In the present description, the term “room temperature” refers to a temperature of about 25 degrees Celsius.

[0046] In the present description, the term “thermoplastic polymer” means a polymer that softens when exposed to heat and returns to its original condition when cooled to room temperature.

[0047] In the present description, the term “ultraviolet photooxidation” refers to the use of ultraviolet radiation in an oxygen- or ozone-rich environment to oxidize a molecular structure, thereby at least partially decompose the molecular structure.

[0048] In some embodiments, oxygen-rich environments have oxygen present in an amount between 10 % by volume to 100 % by volume, alternatively 10 to 90% by volume, alternatively 20-80% by volume; alternatively greater than 20% by volume; alternatively greater than 50% by volume.

[0049] In the case of polymer compositions, the level of decomposition depends upon the structure and components of the polymer composition. Bond energies, the concentration of chromophoric groups, the concentration of impurities or contaminants, the reactivity of hydrogens on secondary and tertiary carbon atoms, oxygen diffusivity, and the presence of stabilizers affect the degree and rate of photodegradation. In some instances, photodegradation initiators are

ketones, quinones, and peroxides. In some instances, pH, temperature, or pressure affect the degree and rate of photodegradation.

[0050] In some embodiments, ultraviolet photooxidation renders polyolefins more polar as well as more reactive or compatible with contaminants. In some embodiments, photooxidation decomposes the contaminants. In some embodiments, the contaminants include non-polyolefin polymers and are oxidized.

[0051] It is believed that nylon 66 is subject to photodecomposition at wavelengths of about 365 nm in the presence of oxygen. It is further believed that nylon 66 is subject to photodecomposition at wavelengths of about 250 nm in the absence of oxygen. The photooxidative processes in polyamides yield chain scissions, formation of hydroxy/hydroperoxy groups, and carbonyl species.

[0052] In the present description, the term “ultraviolet radiation” refers to electromagnetic radiation having wavelengths within the range of about 10 to about 400 nm.

[0053] In the present description, the term “virgin polymers” refers to polymers prepared in polymerization processes from monomers, with or without catalysts or processing aids, and which are yet to be manufactured into first-use consumer or industrial products.

[0054] In the present description, the term “visible-light photooxidation” refers to the use of visible light in an oxygen- or ozone-rich environment to oxidize a molecular structure, thereby at least partially decompose the molecular structure. In some embodiments and when subjected to visible-light photooxidation, the contaminants decompose.

[0055] In the present description, the term “visible-light spectrum” refers to the segment of the electromagnetic spectrum having wavelengths within the range of about 380 to about 700 nm.

[0056] Testing

[0057] ASTM D 792 is entitled “Test Methods for Density and Specific Gravity (Relative Density) of Plastics by Displacement.” The term “ASTM D 792” as used herein refers to the standard test method for determining the specific gravity (relative density) and density of solid plastics in forms such as sheets, rods, tubes, or molded items. The test method includes determining the mass of a specimen of the solid plastic in air, determining the apparent mass of the specimen upon immersion in a liquid, and calculating the specimen’s specific gravity (relative density).

[0058] ASTM D 1238 is entitled “Test Method for Melt Flow Rates of Thermoplastics by Extrusion Plastometer.” The term “ASTM D 1238” as used herein refers to a test method covering the determination of the rate of extrusion of molten thermoplastic resins using an extrusion plastometer. After a specified preheating time, resin is extruded through a die with a specified length and orifice diameter under prescribed conditions of temperature, load, and piston position in the barrel.

[0059] Throughout the present description and claims, the standard melt index values of polyethylene polymers are measured according to ASTM D 1238, using a piston load of 2.16 kg and at a temperature of 190 degrees Celsius. The High Load Melt Index (or HLMI) values are also measured according to ASTM D 1238, but using a piston load of 21.6 kg and at a temperature of 190 degrees Celsius.

[0060] Throughout the present description and claims, the standard melt flow rate values of polypropylene polymers are measured according to ASTM D 1238, using a piston load of 2.16 kg and at a temperature of 230 degrees Celsius.

[0061] ASTM D 1505 is entitled “Standard Test Method for Density of Plastics by the Density-Gradient Technique.” The term “ASTM D 1505” as used herein refers to a test method based on observing the level to which a test specimen sinks in a liquid column exhibiting a density gradient, in comparison with standards.

[0062] For the referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org.

[0063] In a general embodiment, the present disclosure provides a method for recycling plastic waste including a step of photooxidizing the plastic waste, wherein the plastic waste selected from the group consisting of post-consumer recyclate and post-industrial recyclate. In some embodiments, the step of photooxidizing is selected from the group consisting of ultraviolet photooxidizing, visible-light photooxidizing, near-infrared photooxidizing, and oxygen-derived plasma treating. In some embodiments, ultraviolet photooxidizing yields free radicals from the polymeric components. In some embodiments, the free radicals are available for crosslinking or grafting the polymeric components to other components of the plastic waste. In some embodiments, the photooxidizing step is followed by a chain scission step or a secondary oxidizing step.

[0064] In some embodiments, the method for recycling plastic waste further includes a step of comminuting the plastic waste, wherein the comminuting step precedes the photooxidizing step, thereby increasing the surface area of the components of the plastic waste.

[0065] In some embodiments, the method for recycling plastic waste further includes a step of pre-treating the plastic waste with a photo-sensitizer, wherein the pre-treating step precedes the photooxidizing step. In some embodiments, the photosensitizer is selected from the group consisting of metals, peroxides, polyfunctional monomers, and titanium dioxide. In some embodiments, the metal is selected from the group consisting of copper, iron, and zinc.

[0066] In some embodiments, the photooxidizing step occurs in the presence of a photocatalyst. In some embodiments, the photocatalyst is metal-free.

[0067] In some embodiments, the method for recycling plastic waste includes the steps of:

- (a) collecting the plastic waste from residential, commercial, and industrial sites, wherein the plastic waste is selected from the group consisting of post-consumer recycle and post-industrial recycle, and made from or containing a polyolefin and a contaminant;
- (b) photooxidizing the plastic waste;
- (c) melting the plastic waste, thereby yielding a fusion melt; and
- (d) pelletizing the fusion melt, thereby forming a pelletized resin selected from the group consisting of a pelletized, post-consumer recycled (PCR) resin and a pelletized, post-industrial recycled (PIR) resin.

[0068] In some embodiments, the method for recycling plastic waste further includes the steps of:

- (a.i) sorting the plastic waste; and
- (a.ii) cleaning the plastic waste.

[0069] In some embodiments, the method for recycling plastic waste further includes the step of:

- (a.iii) comminuting the plastic waste, thereby increasing the surface area of the components of the plastic waste.

[0070] In some embodiments, the method for recycling plastic waste, wherein step (b) yields free radicals from the polymeric components, further includes the step of:

- (b.i) grafting the free radicals of the polymeric components to other components of the plastic waste, thereby rendering the polymeric components and the other components compatible.

[0071] In some embodiments, the method for recycling plastic waste includes the steps of:

- (a) collecting the plastic waste from residential, commercial, and industrial sites, wherein the plastic waste is selected from the group consisting of post-consumer recyclate and post-industrial recyclate, and made from or containing a polyolefin and a contaminant;
- (a.i) sorting the plastic waste;
- (a.ii) cleaning the plastic waste;
- (a.iii) comminuting the plastic waste, thereby increasing the surface area of the components of the plastic waste;
- (b) photooxidizing the plastic waste, thereby yielding free radicals from the oxidized components;
- (b.i) grafting the free radicals to other components of the plastic waste, thereby rendering the polymeric components and the other components compatible;
- (c) melting the plastic waste, thereby yielding a fusion melt; and
- (d) pelletizing the fusion melt, thereby forming a pelletized resin selected from the group consisting of a pelletized, post-consumer recycled (PCR) resin and a pelletized, post-industrial recycled (PIR) resin.

[0072] In some embodiments, the method for recycling plastic waste include one or more cleaning steps. As previously noted, the mention of one or more method steps does not preclude the presence of additional method steps before or after the combined recited steps or intervening method steps between those steps expressly identified.

[0073] In some embodiments, the plastic waste is made from or containing automobile parts, bleach bottles, food containers, freezer and shopping bags, milk jugs, outdoor furniture, packaging materials, piping, plastic bottles, playground equipment, shampoo bottles, signage and fixtures, toys, and contaminants. In some embodiments, the contaminants are selected from the group consisting of acrylonitrile butadiene styrene (ABS), calcium carbonate, coffee grounds, diapers, dirt, fillers, food stuffs, glass, grass, labels, metals (including aluminum), nylon, other inorganics, other polymers, paper, plant stems, polycarbonates, polyethylene terephthalate (PET), processing additives, property-imparting additives, rubbers, and wood.

[0074] In some embodiments, the present disclosure provides a post-consumer recycled resin prepared from a post-consumer recyclate, wherein the resin is selected from the group consisting of polyethylene and polypropylene. In some embodiments, the polyethylene is a high-density polyethylene.

[0075] In some embodiments, the present disclosure provides a post-industrial recycled resin prepared from a post-industrial recycle, wherein the resin is selected from the group consisting of polyethylene and polypropylene.

[0076] In some embodiments, the present disclosure provides a polymer composition made from or containing resin selected from the group consisting of a post-consumer recycled resin and a post-industrial recycled resin. In some embodiments, the polymer composition is made from or containing:

- (a) from 5 % by weight to 95 % by weight, based upon the total weight of the polymer composition, of a resin selected from the group consisting of a post-consumer recycled resin and a post-industrial recycled resin; and
- (b) from 5 % by weight to 95 % by weight, based upon the total weight of the polymer composition, of a virgin polymer.

[0077] In some embodiments, the resin is selected from the group consisting of HDPE PCR and PP PCR. In some embodiments, the resin is the base resin of the polymer composition. In some embodiments, the resin is a complementary resin. In some embodiments, the resin is a component in an additive composition or a filler, for use with a virgin or other PCR resin. In some embodiments, the resin is used as a filler in amount up to 50 % by weight, alternatively from 0.5 % by weight to 30 % by weight, alternatively from 1.0 % by weight to 20% by weight, based upon the total weight of the polymer composition.

[0078] In some embodiments, the resin bears the International Code Council (ICC) Certification.

[0079] In some embodiments, the polymer composition is further made from or containing an additive composition. In some embodiments, the additive composition imparts properties such as thermal stability, light and ultraviolet protection, and color. In some embodiments, the additive composition is present in an amount from 0.05 % by weight to 10 % by weight, alternatively from 0.1 % by weight to 8 % by weight, based upon the total weight of the polymer composition.

[0080] In some embodiments, the present disclosure provides an article of manufacture made from or containing a resin selected from the group consisting of post-consumer recycled resins and post-industrial recycled resins. In some embodiments, the article of manufacture is selected from the group consisting of blow-molded articles, films, flexibles, injection-molded articles, packaging, and piping. In some embodiments, the article of manufacture is useful in non-cosmetic-intensive, post consumer recycled resin applications, including agricultural film and trash bags.

EXAMPLES

[0081] The following examples are included to demonstrate embodiments. The techniques disclosed in the examples constitute exemplary modes of practice. Changes can be made in the specific embodiments which are disclosed and still obtain a like or similar result without departing from the spirit and scope of this disclosure.

[0082] For the comparative examples and the examples of an embodiment, various compounds were formulated to prepare test specimen. The materials were admixed in the weight percents shown in Table 1.

[0083] Example No. 1

[0084] Post-consumer HDPE regrind is purchased for use as Example No. 1 feedstock.

[0085] Twenty (20) pounds of the feedstock is loaded into a ribbon blender, fitted with a variable wavelength light source. While blending the feedstock, the wavelength of the variable wavelength light source is set to 365 nm (within the ultraviolet range). The feedstock is exposed to the ultraviolet radiation for two (2) hours.

[0086] The resulting composition is pelletized using a twin-screw extruder with a strand pelletizer.

[0087] Example No. 2

[0088] Post-consumer HDPE regrind is purchased for use as Example No. 2 feedstock.

[0089] Twenty (20) pounds of the feedstock is loaded into a ribbon blender, fitted with a variable wavelength light source. While blending the feedstock and in an amount to provide 2% by weight based upon the total weight of the resulting blend, Trigonox™ 101 2,5-dimethyl-2,5-di(tert-butylperoxy) hexane) is added to the feedstock.

[0090] The wavelength of the variable wavelength light source is set to 365 nm (within the ultraviolet range). The blend is exposed to the ultraviolet radiation for two (2) hours.

[0091] The resulting composition is pelletized using a twin-screw extruder with a strand pelletizer.

[0092] Example No. 3

[0093] Post-consumer HDPE regrind is purchased for use as Example No. 3 feedstock.

[0094] Twenty (20) pounds of the feedstock is loaded into a ribbon blender, fitted with a variable wavelength light source. While blending the feedstock and in an amount to provide 2%

by weight based upon the total weight of the resulting blend, Ti-Pure™ R-101 rutile titanium dioxide (TiO₂) pigment is added to the feedstock.

[0095] The wavelength of the variable wavelength light source is set to 365 nm (within the ultraviolet range). The blend is exposed to the ultraviolet radiation for two (2) hours.

[0096] The resulting composition is pelletized using a twin-screw extruder with a strand pelletizer.

[0097] Example No. 4

[0098] Post-consumer HDPE regrind is purchased for use as Example No. 4 feedstock.

[0099] Twenty (20) pounds of the feedstock is loaded into a ribbon blender, fitted with a variable wavelength light source. While blending the feedstock and in an amount to provide 2% by weight based upon the total weight of the resulting blend, maleic anhydride is added to the feedstock.

[0100] The wavelength of the variable wavelength light source is set to 365 nm (within the ultraviolet range). The blend is exposed to the ultraviolet radiation for two (2) hours.

[0101] The resulting composition is pelletized using a twin-screw extruder with a strand pelletizer.

[0102] Example No. 5

[0103] Post-consumer HDPE regrind is purchased for use as Example No. 5 feedstock.

[0104] Twenty (20) pounds of the feedstock is loaded into a ribbon blender, fitted with a variable wavelength light source. While blending the feedstock, the blender is flushed with ozone, thereby providing an ozone-rich environment, and the wavelength of the variable wavelength light source is set to 365 nm (within the ultraviolet range). The feedstock is exposed to the ozone-rich environment and ultraviolet radiation for two (2) hours.

[0105] The resulting composition is pelletized using a twin-screw extruder with a strand pelletizer.

[0106] Comparative Example No. 6

[0107] Post-consumer HDPE pellets is purchased for use as Comparative Example No. 6.

[0108] Physical Properties of Blow-Molded Bottles

[0109] A blow molder is used to prepare 1-gallon bottles from each set of pellets. The pellets are loaded into a hopper, and used to produce 100 bottles with a weight of 155 grams.

[0110] The resulting bottles are compared for crush performance, drop impact, and environmental stress crack resistance (ESCR).

[0111] Crush performance is determined by placing an empty bottle on flat platens. The distance between the platens is decreased at a rate of 2"/min. The yield point for each set of bottles is recorded.

[0112] Drop impact is determined by filling an empty bottle to capacity with water. The bottle is conditioned to room temperature overnight.

[0113] The Bruceton staircase method is used to determine the F50 drop height for each set. That is, bottles are impact tested at various heights. Specifically, if the bottle does not fail at the initial height, the height is increased incrementally by one foot until failure occurs. After failure has occurred, the height is decreased by the same increment (that is, one foot) and the process is repeated until the samples are utilized. The F50 is then calculated.

[0114] Environmental stress crack resistance (ESCR) is determined by filling each bottle to one third of the bottle's capacity with a 10% Igepal solution. The partially-filled bottles is placed in an oven at 50°C and then checked daily for failures. The number of days to failure is recorded.

[0115] It should be understood that various changes, substitutions and alterations can be made herein without departing from the spirit and scope of this disclosure as defined by the appended claims. Moreover, the scope of the present application is not intended to be limited to the particular embodiments of the process, machine, manufacture, composition of matter, means, methods and steps described in the specification. As one of the ordinary skill in the art will readily appreciate from the disclosure, processes, machines, manufacture, compositions of matter, means, methods, or steps, presently existing or later to be developed that perform the same function or achieve the same result as the corresponding embodiments described herein can be utilized. Accordingly, the appended claims are intended to include within their scope such processes, machines, manufacture, compositions of matter, means, methods, or steps.

CLAIMS

What is claimed is:

1. A method for recycling plastic waste and preparing a pelletized resin comprising the steps of:
 - (a) collecting the plastic waste from residential, commercial, and industrial sites, wherein the plastic waste is selected from the group consisting of post-consumer recycle and post-industrial recycle, and comprising the polyolefin and the contaminant;
 - (b) photooxidizing the plastic waste;
 - (c) melting the plastic waste, thereby yielding a fusion melt; and
 - (d) pelletizing the fusion melt, thereby forming a pelletized resin selected from the group consisting of a pelletized, post-consumer recycled (PCR) resin and a pelletized, post-industrial recycled (PIR) resin.
2. The method for recycling plastic waste of Claim 1, wherein the plastic waste comprises automobile parts, bleach bottles, food containers, freezer and shopping bags, milk jugs, outdoor furniture, packaging materials, piping, plastic bottles, playground equipment, shampoo bottles, signage and fixtures, toys, and contaminants.
3. The method for recycling plastic waste of Claim 2, wherein the contaminants are selected from the group consisting of acrylonitrile butadiene styrene (ABS), calcium carbonate, coffee grounds, diapers, dirt, fillers, food stuffs, glass, grass, labels, metals (including aluminum), nylon, other inorganics, other polymers, paper, plant stems, polycarbonates, polyethylene terephthalate (PET), processing additives, property-imparting additives, rubbers, and wood.
4. The method for recycling plastic waste of Claim 3, wherein the contaminants are nylons.
5. The method for recycling plastic waste of Claim 1, further comprising the steps of
 - (a.i) sorting the plastic waste;
 - (a.ii) cleaning the plastic waste; and
 - (a.iii) comminuting the plastic waste, thereby increasing the surface area of the components of the plastic waste.
6. The method for recycling plastic waste of Claim 1, wherein the photooxidizing step (b) yields free radicals from the polymeric components, further comprising the step of

- (b.i) grafting the free radicals of the polymeric components to other components of the plastic waste, thereby rendering the polymeric components and the other components compatible.
7. The method for recycling plastic waste of Claim 1, wherein the step of photooxidizing is selected from the group consisting of ultraviolet photooxidizing, visible-light photooxidizing, near-infrared photooxidizing, and oxygen-derived plasma treating.
 8. The method for recycling plastic waste of Claim 1, wherein the resin is selected from the group consisting of polyethylene and polypropylene.
 9. A pelletized, post-consumer recycled resin comprising (a) resin selected from the group consisting of polyethylene and polypropylene and (b) contaminants, prepared via photooxidization of plastic waste.
 10. An article of manufacture comprising the pelletized, post-consumer recycled resin of Claim 9.

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US2023/025994

A. CLASSIFICATION OF SUBJECT MATTER

IPC(8) - INV. - B29B 17/02; B29B 17/04; C08J 11/10; B01J 19/12 (2023.01)

ADD. - C08L 23/06 (2023.01)

CPC - INV. - B29B 17/0036; B29B 17/0412; C08J 11/10; B01J 19/123 (2023.08)

ADD. - C08L 23/06; B01J 2219/1203 (2023.08)

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)

See Search History document

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

See Search History document

Electronic database consulted during the international search (name of database and, where practicable, search terms used)

See Search History document

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2022/029318 A1 (APK AG) 10 February 2022 (10.02.2022) entire document	9, 10
Y		1-5, 7, 8
Y	US 2002/0179424 A1 (OSADA et al.) 05 December 2002 (05.12.2002) entire document	1-5, 7, 8
Y	WO 2021/163102 A1 (EASTMAN CHEMICAL COMPANY) 19 August 2021 (19.08.2021) entire document	4
A	WO 2010/036243 A1 (DOW GLOBAL TECHNOLOGIES INC) 01 April 2010 (01.04.2010) entire document	1-10

☐ Further documents are listed in the continuation of Box C.☐ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"D" document cited by the applicant in the international application

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"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

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

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