

BIODEGRADABLE EXTRUSION COATING PROCESS**TECHNICAL FIELD**

[0001] The disclosure is directed to biodegradable materials and, in particular, to a biodegradable extrusion coating and a method for coating a substrate with the biodegradable extrusion coating.

BACKGROUND AND SUMMARY

[0002] Coatings are ubiquitous in packaging, providing a barrier for grease, moisture, and oxygen. While polymeric coatings can be applied with various methods, a common method used in paperboard packaging is extrusion coating, where the most utilized polymeric materials are polyolefins, such as polyethylene and polypropylene. Extrusion coating technology is found in almost every paperboard-based packaging application currently in the market today.

[0003] In the extrusion process, the polymer is melted and extruded through a slot die positioned above a moving web of paperboard oriented horizontally. The extrudate falls from the die, forming a "melt curtain" that contacts and coats the surface of the paperboard as the paperboard is pulled through the coating station. The thus-coated paperboard is then pulled through one or more sets of nip and/or chill rollers to promote adhesion between the layers and further cool the coating material.

[0004] The slot die gap is typically greater than the coating thickness. Therefore, the melt curtain must be thinned, typically to one-tenth to one-eightieth of the die gap, as the extrudate falls from the die to the moving web of the paperboard. This thinning is accomplished largely by adjusting the "air gap," i.e., the vertical distance between the die and the moving web, and the line speed, i.e., the rate at which the moving web is pulled through the coating station.

[0005] In extrusion coating, a material is extruded through a die, forming a continuous curtain of molten material. A paperboard web is then run under this curtain of molten material to apply a specified coat weight to the paperboard web. The paperboard web is then run through cooling rollers to solidify the molten material before being wound for storage, transportation, and conversion into packaging. However, conventional polyolefin extrusion coatings prevent the packaging from being fully biodegradable.

[0006] Poly(hydroxyalkanoate)--based (PHA-based) materials are an excellent alternative to polyolefin coatings, as the PHA-based materials can be designed to be home-

compostable and marine degradable. Unfortunately, poly(hydroxyalkanoate)-based extrusion coatings cannot be run using conventional extrusion coating techniques. With conventional polyolefin-based extrusion coatings, the molten polymer on the substrate is contacted by rollers chilled to 20 °C or below. Chilling the rollers helps quickly crystallize the molten polymer, preventing the polymer from sticking to the rollers. If the coating sticks to the roll, the coated paper will break, and the line will stop, requiring rewinding, which is an extremely time-consuming process. When PHA-based coatings are run under the same conditions, the chilled rollers induce the sticking of the polymer to the rollers so that the polymer wraps around the chilled rollers. Accordingly, what is needed is a method for extruding PHA-based coatings onto packaging substrates without adversely affecting coating equipment operations and run time.

[0007] In view of the foregoing, embodiments of the disclosure provide a method for extruding a poly(hydroxyalkanoate)-based (PHA-based) material onto a packaging substrate and a packaging substrate containing the poly(hydroxyalkanoate)-based coating. The method includes extruding a molten poly(hydroxyalkanoate) film through a die or slot die onto a moving web of the packaging substrate to provide a coated substrate. A coated side of the coated substrate is contacted with a chill roller to crystallize the molten film on the coated substrate, wherein the chill roller has a temperature ranging from about 30 to about 60 °C.

[0008] In some embodiments, the chill roller has a temperature ranging from about 30 °C to about 60 °C, and preferably from about 37 °C to about 55 °C.

[0009] In some embodiments, an air gap distance between the die or slot die and the moving web of packaging material ranges from about 2.54 centimeters to less than about 20 centimeters, and more preferably from about 2.54 centimeters to about 13 centimeters.

[00010] In some embodiments, the coating weight of molten film on the coated substrate ranges from about 4 grams/m² to about 200 grams/m².

[00011] In some embodiments, the coating thickness of molten film on the coated substrate ranges from about 5 microns to about 200 microns.

[00012] In some embodiments, the moving web of the packaging substrate has a line speed ranging from 50 to 800 meters per minute.

[00013] In some embodiments, the amount of poly(hydroxyalkanoate) in the molten film ranges from about 50 to about 99 weight percent based on the total weight of the molten film.

[00014] In some embodiments, the moving web of the packaging substrate is treated prior to the extruding step with a pre-treat process selected from flame treating, corona treating, ozone treating, and a combination thereof. In other embodiments, the moving web of packaging substrate is flame treated to a temperature ranging from about 25 °C to about 60 °C.

[00015] In some embodiments, the chill roller comprises a release or non-stick coating including, but not limited to, a polytetrafluoroethylene coating configured to prevent the molten film from sticking to or wrapping around the chill roller.

[00016] In some embodiments, the chill roller has a surface feature selected from the group consisting of a smooth surface, a rough surface, a matte surface, and a shiny surface.

[00017] In some embodiments, the extrusion step is carried out at a temperature of less than about 210 °C.

[00018] In some embodiments, the extrusion step uses an ultra-low-shear screw extruder, or a low-shear screw extruder with a compression ratio below 3.5, and more preferably a compression ratio of less than 3.0.

[00019] In some embodiments a paperboard web contains a poly(hydroxyalkanoate) coating made by extruding a molten poly(hydroxyalkanoate) through a die or slot die onto a moving web of the packaging substrate to provide a coated substrate. A coated side of the coated substrate is contacted with a chill roller to crystallize the molten film on the coated substrate, wherein the chill roller has a temperature ranging from about 30 °C to about 60 °C.

[00020] An advantage of the disclosed embodiments is that they provide a process for coating a substrate, such as a paperboard substrate with a biodegradable PHA-based coating material, using conventional extrusion coating processes and equipment without major changes to the equipment or processes.

BRIEF DESCRIPTION OF THE DRAWINGS

[00021] FIG. 1 is a side schematic illustration of a PHA-based coating process according to the disclosure.

[00022] FIG. 2 is a perspective schematic view of the coating process of FIG. 1.

DETAILED DESCRIPTION

[00023] As used herein, the term "biodegradable" refers to a plastic or polymeric material that will undergo biodegradation by living organisms (microbes) in anaerobic and aerobic environments (as determined by ASTM D5511), in soil environments (as determined by ASTM 5988), in freshwater environments (as determined by ASTM D5271 (EN 29408)), or in marine environments (as determined by ASTM D6691). The biodegradability of biodegradable plastics can also be determined using ASTM D6868 and European EN 13432.

[00024] The polymeric coatings of the present disclosure are preferably also "compostable," as determined by ASTM D6400 for industrial compostability.

[00025] In particular, the biodegradable polymeric coating compositions include poly(hydroxyalkanoates) as the biodegradable polymer. The composition is generally made up of from about 5 weight percent to about 95 weight percent poly(hydroxyalkanoates) (PHAs). More preferably, the composition is made up of about 20 weight percent to about 90 weight percent poly(hydroxyalkanoates). Still, more preferably, the polymeric composition includes from about 30 weight percent to about 80 weight percent PHAs, such as from about 40 weight percent to about 70 weight percent PHAs.

[00026] In some instances, the PHAs used to make the biodegradable coatings are preferably made up of a mixture of monomeric units. Accordingly, the PHAs may include from about 90 to about 99.9 mole percent monomer residues of 3-hydroxybutyrate and from about 0.1 to about 10 mole percent monomer residues of a second 3-hydroxyalkanoate having from 5 to 12 carbon atoms. In one embodiment, a poly(hydroxyalkanoate) containing from about 97 to about 99 mole percent monomer residues of 3-hydroxybutyrate and from about 1 to about 3 mole percent monomer residues of a 3-hydroxyhexanoate may be used to make the PHA-based coating.

[00027] The PHA-based coating may also include a second biodegradable polymer selected from the group consisting of poly(butylene succinate), poly(butylene succinate-co-adipate), poly(lactic acid), cellulose esters (such as cellulose acetate), poly(butylene adipate-co-terephthalate), thermoplastic starch, and mixtures thereof. The amount of this second biodegradable polymer is typically from about 10 weight percent to about 90 weight percent of the total coating composition, such as from about 20 to about 80 weight percent or from about 30 to about 50 weight percent of the total weight of the coating composition.

[00028] In some instances, the second biodegradable polymer may include poly(lactic acid) in an amount from about 10 weight percent to about 90 weight percent of the polymeric composition. More preferably, the coating composition includes from about 20 weight percent to about 60 weight percent poly(lactic acid), such as from about 30 to about 50 weight percent poly(lactic acid) based on the total weight of the PHA-based coating composition.

[00029] In general, the poly(hydroxyalkanoate) polymer has a weight average molecular weight from about 50,000 Daltons to about 7.5 million Daltons and, more preferably, has a weight average molecular weight from about 300,000 Daltons to about 3.0 million Daltons as determined by ASTM D6474-20.

[00030] In certain embodiments, the poly(hydroxyalkanoate) and at least one biodegradable polymer are melt-blended together in an extrusion process.

[00031] In some embodiments, a transesterification reaction is carried out by reacting the poly(hydroxyalkanoate) and at least one biodegradable polymer with each other in a reactive extrusion process.

[00032] In some embodiments, a nucleating agent may be present in the polymeric coating composition in an amount from about 0.1 weight percent to about 5 weight percent. In certain embodiments, the nucleating agent may be selected from erythritols, pentaerythritol, dipentaerythritols, artificial sweeteners, stearates, polysaccharides, sorbitols, mannitols, inositols, polyester waxes, nanoclays, behenamide, erucamide, stearamide, oleamide, polyhydroxybutyrate, thymine, cyanuric acid, cytosine, adenine, uracil, guanine, boron nitride and mixtures thereof.

[00033] According to certain embodiments, the polymeric coating includes from about 0.05 weight percent to about 3 weight percent of at least one melt strength enhancer selected from the group consisting of a multifunctional epoxide; an epoxy-functional, styrene-acrylic polymer; an organic peroxide, such as a tert-butyl peroxybenzoate; an oxazoline; a carbodiimide; reactive and secondary polymers such as poly(vinyl acetate), and mixtures thereof.

[00034] The polymeric coating composition may also include an optional plasticizer material. Suitable materials for the plasticizer are typically selected from the group consisting of sebacates, citrates, fatty esters of adipic, succinic, and glucaric acids, lactates, alkyl diesters, citrates, alkyl methyl esters, dibenzoates, propylene carbonate, caprolactone diols having a number average molecular weight from 200-10,000 g/mol as determined by ASTM D6474-20, poly(ethylene glycols) having a number average molecular weight of 400-10,000 g/mol as

determined by ASTM D6474-20, esters of vegetable oils, long chain alkyl acids, adipates, glycerol, isosorbide derivatives or mixtures thereof, polymeric plasticizers, poly(hydroxyalkanoates) copolymers comprising at least 18 mole percent monomer residues of hydroxyalkanoates other than hydroxybutyrate, and mixtures thereof.

[00035] The amount of plasticizer in the polymeric coating composition may be up to about 15 weight percent. More preferably, the polymeric coating composition is made up of from about 1 weight percent to about 8 weight percent of the plasticizer.

[00036] Moreover, in some instances, the polymeric coating composition may include up to 50 weight percent of one or more additives selected from the group consisting of poly(vinyl alcohols), poly(vinyl acetate), poly(vinyl laurate), poly(ethylene vinyl acetate), poly(glycolic acid), furandicarboxylic acid-based polyesters, cellulose, nanocellulose, glucans, and mixtures thereof. Minor amounts of other biopolymers, other polymers, nucleating agents, chain extenders, fatty amides, and fillers may also be used in the coating compositions described herein.

[00037] In general, the at least one poly(hydroxyalkanoate) polymer has a weight average molecular weight from about 50,000 Daltons to about 7.5 million Daltons and, more preferably, has a weight average molecular weight from about 300,000 Daltons to about 3.0 million Daltons as determined by ASTM D6474-20.

Crystallinity

[00038] The volume percent crystallinity (Φ_c) of a semi-crystalline polymer (or copolymer) often determines what type of end-use properties the polymer possesses. For example, highly (greater than 50%) crystalline polyethylene polymers are strong and stiff and suitable for products such as plastic milk containers. On the other hand, low crystalline polyethylene is flexible and tough and suitable for products such as paperboard coatings, food wraps, and garbage bags. Crystallinity can be determined in several ways, including x-ray diffraction, differential scanning calorimetry (DSC), density measurements, and infrared absorption. The most suitable method depends upon the material being tested.

[00039] The volume percent crystallinity (Φ_c) of the poly(hydroxyalkanoate) copolymer may vary depending on the mol percentage of poly(3-hydroxyhexanoate) in the poly(hydroxyalkanoate) copolymer. The addition of poly(3-hydroxyhexanoate) effectively lowers the volume percent crystallinity of the poly(hydroxyalkanoate) copolymer, crystallization rate, and

melting temperature while providing an increase in the flexibility of the copolymer. As described herein, nucleating agents may be used to speed up the crystallization process of the poly(hydroxyalkanoate) copolymers.

[00040] In general, poly(hydroxyalkanoates) of the type described herein for use in the making of the coating compositions preferably have a crystallinity of from about 0.1% to about 99% as measured via x-ray diffraction; more preferably from about 2% to about 80%, more preferably still from about 20% to about 70%.

Melt Temperature

[00041] Preferably, the biodegradable poly(hydroxyalkanoates) of the present invention have a melt temperature (T_m) of from about 60 °C. to about 200 °C, more preferably from about 80 °C. to about 190 °C, more preferably still from about 130 °C. to about 160 °C.

[00042] A suitable PHA-based composition for coating paperboard substrates is exemplified in the following table.

Component	Weight %
Poly(hydroxyalkanoate)	59.02
Pentaerythritol	0.88
Poly(lactic acid)	40.00
Tert-butyl peroxide	0.10

[00043] With reference now to FIGs. 1-2, a process 10 for coating a paperboard substrate is illustrated. While the illustrated process shows coating only on one side, in some embodiments, the PHA-based coating may be applied to both sides of the paperboard substrate.

[00044] The coating process 10 includes a supply roll 12 of a substrate, such as a paperboard substrate 14. Prior to applying the coating, the substrate 14 web is treated with a process selected from flame treatment, corona treatment, ozone treatment, or a combination thereof in a pre-treatment step 16. In a particularly suitable embodiment, the substrate 14 web is flame treated to a temperature ranging from about 25 to about 60 °C to improve the adhesion of the PHA-based coating to the substrate. When running without a flame treater, the adhesion of the PHA-based material to the substrate 14 web is inconsistent. The extrusion process may require higher processing temperatures or lower air gaps (described in more detail below). It is believed that flame treatment promotes the adhesion of the PHA-based material to the substrate 14 web by oxidizing the surface of the substrate 14 web and heating the surface thereof. Heating the surface allows the PHA-based material to continue to flow into the fibers of the substrate 14 web once the

material hits the substrate 14 web instead of crystallizing quickly after hitting an untreated, cold surface. Without this treatment, adhesion of the PHA-based material to the substrate 14 web may be low, creating issues with the final article's performance.

[00045] In some embodiments, the coating is extruded onto the paperboard substrate without first pre-treating the paperboard substrate. In other embodiments, the substrate is pre-treated by an ozone treatment and flame treatment or by a corona treatment and flame treatment.

[00046] The substrate 14 web is then fed to a die or slot-die extruder 18 wherein a molten film 20 of PHA-based material is applied to the substrate 14 web. The extruder may be an ultra-low-shear screw extruder, or a low-shear screw extruder, with a compression ratio below 3.5 and more preferably a compression ratio of less than 3.0. The molten film is extruded at a temperature below 210 °C, such as less than about 200 °C, onto the substrate 14 web. At a temperature above about 190 °C, there is more likelihood that the coating will stick to the chill roller or that the molten film curtain 20 will become unstable.

[00047] The slot die extruder 18 has a horizontally oriented slit with its length traverse to the direction of travel of the substrate 14 web indicated by arrow 22. A slit opening in the slot die extruder 18 sets the thickness of film curtain 20 of the PHA-based material as it exits slot die extruder 18. The die gap may be, for example, at least 0.15 mm, at least 0.25 mm, or at least 0.30 mm and may be, for example, up to 2.5 mm, up to 1.5 mm, up to 1 mm, up to 0.85 mm, or up to 0.70 mm.

[00048] As the substrate 14 web is continuously pulled through an area below the slot die extruder 18, the film curtain 20 falls in the direction indicated by arrow 24 onto the substrate 14 web and forms a coating thereon. As shown, coated substrate 14 web is fed from roll 12, over nip roller 26 and chill roller 28. Nip roller 26 and/or chill roller 5 may be driven and thus may provide the necessary force to pull substrate 14 web through coating zone 30. Alternatively, or in addition, various drive mechanisms may be located downstream (i.e., in the direction of travel of substrate 14 web), which mechanisms pull substrate 14 web through coating zone 30 (and the rest of the process).

[00049] Because coating zone 30 is located below slot die extruder 18, film curtain 20 must fall downward through the atmosphere from a slit opening into coating zone 30, which contacts the substrate 14 web and forms a coating thereon. Pressure is then applied to the coated substrate 32 to marry the layers together and promote good adhesion. The coating is cooled ("quenched") to

below its crystallization temperature, preferably to a temperature ranging from about 30 °C to about 60 °C, preferably from about 37 °C to about 55 °C. The foregoing pressure and cooling steps can be performed sequentially (applying pressure followed by cooling) or simultaneously. In the embodiment shown in FIGs 1-2, pressure is applied by passing the coated substrate 32 between the nip roller 26 and chill roller 28. The applied pressure may range from about 101 to 2020 kPa actual, such as from about 202 to 1010 kPa actual. Chill roller 28 must be maintained at a temperature above 25 °C., with a preferred temperature ranging from about 30 to about 60 °C. It has been found, quite surprisingly, that cooling the coated web below about 30 °C causes the coating to stick to the chill roller 28 rather than to the substrate 14 web.

[00050] In some embodiments, the chill roller may be coated with a non-stick coating. A suitable non-stick coating may include a polytetrafluoroethylene coating that is configured to prevent the molten PHA-based material from sticking to or wrapping on the chill roller.

[00051] Another important feature of the process of coating a substrate web with a PHA-based coating is maintaining a suitable air gap between the slot die extruder and the substrate 14 web. The vertical distance between the slit opening in the slot die extruder 18 and the point of contact of the film curtain 20 with substrate 14 web is known as the "air gap," which is indicated in FIG. 2 by reference numeral 34. The air gap 34 is preferably as small as possible, consistent with geometrical constraints imposed by the design of the equipment (in particular, the chill roller 28 diameter), so cooling is minimized in the film curtain 20. The viscosity of the PHA-based coating material does not increase excessively before coming into contact with the substrate 14 web. For polyolefin coatings, the air gap is high, as polyolefins will undergo oxidation in the air gap, which will help with adhesion. PHA-based materials, however, require a very low air gap. PHA does not undergo oxidation, so long exposure times are unnecessary, and higher air gaps decrease adhesion with PHA-based material to the substrate 14 web. The decreased adhesion results from the PHA-based composition cooling in the air gap. If the PHA-based composition cools too much before reaching the substrate, the PHA-based material will crystallize before penetrating the substrate and will result in poor performance during further conversion. Polyethylene typically has an air gap of 3-10 inches (7.6 cm to 25.4 cm). PHA-based compositions run best when the air gap is less than 15 cm, with lower air gaps giving better adhesion. The air gap 34 must be no more than 15 centimeters, such as from about 2.0 centimeters to less than about 20 centimeters or from about 2.54 centimeters to about 13 centimeters. The temperature of the

atmosphere through which film curtain 20 falls may be maintained by localized heating of the film curtain 20 in the air gap 34. The temperature of the film curtain 20 can be measured, for example, using infrared thermal imaging methods.

[00052] The film curtain 20 draws down to become much thinner as it passes through the air gap 34 to form a coating on the substrate 14 web. The drawing effect is due in part to the effect of gravity and in part due to the film curtain 20 adhering to the traveling substrate 14 web. The movement of substrate 14 web, therefore, pulls on the film curtain 20 and draws it down. The extent of this drawing can be expressed as the draw ratio, i.e., the ratio of the die gap and the thickness of the applied coating. For example, the draw ratio may be as small as about 10 and as great as about 80. The invention has particular benefits when the coating process is operated at higher draw ratios, such as 40 to 80, 42 to 75, or 50 to 75.

[00053] The coating thickness may range from about 5 microns to about 200 microns, such as from about 10 microns to about 180 microns, about 20 microns to about 160 microns, or about 30 microns to about 140 microns, and all ranges in between.

[00054] The width of the film curtain 20 is typically less than the length of the slit opening of the slit in the slot die extruder 18. This phenomenon is known as "neck-in." At higher draw ratios, a periodic variation in the amount of neck-in (or, equivalently, the width of the applied coating) is often experienced in melt extrusion coating processes. This is commonly referred to as "edge weave" and is disadvantageous because the substrate becomes coated unevenly along the opposing edges (aligned with the direction of movement of the substrate through the coating application area), which requires trimming or scrapping of the coated product.

[00055] On an industrial scale, the line speed greatly affects the draw ratio, with higher line speeds correlating to higher draw ratios (other things being constant). "Line speed" refers to the linear rate of movement of the substrate 14 web through the coating zone 30. For example, the line speed may range from at least 50 meters per minute to about 800 meters per minute. A preferred line speed is at least 80 meters per minute, at least 100 meters per minute, at least 120 meters per minute, or at least 140 meters per minute. The upper range of line speed may be, for example, up to 800 meters per minute, up to 500 meters per minute, up to 300 meters per minute, up to 250 meters per minute, up to 200 meters per minute, up to 180 meters per minute or up to 160 meters per minute.

[00056] The substrate 14 web may be selected from a cellulosic material such as paperboard, paper, cardboard, a wood veneer, or other board stock; a textile, which may be, for example, made up of woven, knitted, entangled, and/or melt-bonded fibers; a composite material; or any other material that is capable of being processed through the melt extrusion coating apparatus. Thin, flexible substrates that can be rolled without damage are preferred, and paper and paperboard are especially preferred.

[00057] Paperboard has an area density of at least 224 g/m², whereas paper has a lower area density. A paper or paperboard substrate 14 web may be, for example, a solid bleached sulfate type, an unbleached Kraft type, or a recycled paperboard, which may or may not have a kaolin or other coating on at least one surface. The substrate calipers may be, for example, from 0.002 to 0.050 mils (50.8 to 1270 microns), especially 0.01 to 0.05 mils (254 to 1270 microns), as measured by ASTM D645-95.

[00058] In some embodiments, the PHA-based composition forms an exposed layer in the final product. In such a case, the PHA-based composition may impart moisture resistance to the coated substrate 14 web by forming a barrier against water penetration (or other liquid) to the underlying substrate. The coated substrate is particularly suitable for making certain packaging materials and disposable food service items such as drink cups. Coated substrates used in making such packaging materials and food service items may be coated with the PHA-based composition on one or both sides. Paperboard for making cold food or cold beverage containers, for example, is typically coated on both sides to protect the paperboard substrate from contact with the container contents on the inside surface as well as from condensation that forms on the outside surface.

[00059] The PHA-based composition may be used to form an adhesive layer between two substrates. In a melt extrusion process, the coating is formed onto one layer as described before, and a second substrate layer is laid over the coating before it is quenched to form the assembly.

[00060] The foregoing process may be used to run PHA-based materials as coatings for paperboard substrates on traditional extrusion coating equipment. Without using the specific operational parameters described herein, it has been found that the PHA-based compositions cannot be extrusion-coated onto a paperboard substrate because the molten PHA-based film tends to wrap on the chill roller rather than coat the paperboard substrate.

[00061] The present disclosure is also further illustrated by the following embodiments:

[00062] Embodiment 1: A method for extruding a poly(hydroxyalkanoate)-based material onto a packaging substrate, comprising:

extruding a molten film comprising poly(hydroxyalkanoate) through a die or slot die onto a moving web of the packaging substrate to provide a coated substrate; and

contacting a coated side of the coated substrate with a chill roller to crystallize the molten film on the coated substrate, wherein the chill roller has a temperature ranging from about 30 °C to about 60 °C.

[00063] Embodiment 2. The method of embodiment 1, wherein the chill roller has a temperature ranging from about 30 °C to about 60 °C, and more preferably from about 37 °C to about 55 °C.

[00064] Embodiment 3. The method of embodiment 1 or embodiment 2, wherein an air gap distance between the die or slot die, and the moving web of packaging material ranges from about 2.54 centimeters to less than about 20 centimeters, and more preferably from about 2.54 centimeters to about 13 centimeters.

[00065] Embodiment 4. The method of any of the preceding embodiments, wherein a coating weight of molten film on the coated substrate ranges from about 4 grams/m² to about 200 grams/m².

[00066] Embodiment 5. The method of any of the preceding embodiments, wherein a coating thickness of molten film on the coated substrate ranges from about 5 microns to about 200 microns.

[00067] Embodiment 6. The method of any of the preceding embodiments, wherein the moving web of packaging substrate has a line speed ranging from 50 to 800 meters per minute.

[00068] Embodiment 7. The method of any of the preceding embodiments, wherein the amount of poly(hydroxyalkanoate) in the molten film ranges from about 50 to about 99 weight percent based on a total weight of the molten film.

[00069] Embodiment 8. The method of any of the preceding embodiments, further comprising treating the moving web of packaging substrate prior to the extruding step with a pre-treat process selected from flame treating, corona treating, ozone treating, and a combination thereof.

[00070] Embodiment 9. The method of embodiment 8, wherein the moving web of packaging substrate is flame treated to a temperature ranging from about 25 °C to about 60 °C.

[00071] Embodiment 10. The method of any of the preceding embodiments, wherein the chill roller comprises a release or non-stick coating including, but not limited to, a polytetrafluoroethylene coating configured to prevent the molten film from sticking to or wrapping around the chill roller.

[00072] Embodiment 11. The method of any of the preceding embodiments, wherein the chill roller has a surface feature selected from the group consisting of a smooth surface, a rough surface, a matte surface, and a shiny surface.

[00073] Embodiment 12. The method of any of the preceding embodiments, wherein the extrusion step is carried out at a temperature of less than about 210 °C.

[00074] Embodiment 13. The method of any of the preceding embodiments, wherein the extrusion step is carried out using an ultra-low-shear, or low shear screw extruder with a compression ratio below 3.5 and more preferably a compression ratio of less than 3.0.

[00075] Embodiment 14. A paperboard web comprising a poly(hydroxyalkanoate) coating made by the method of any of the preceding embodiments.

[00076] The foregoing descriptions of preferred embodiments for this invention have been presented for purposes of illustration and description. They are not intended to be exhaustive or to limit the invention to the precise form disclosed. Obvious modifications or variations are possible in light of the above teachings. The embodiments are chosen and described in an effort to provide the best illustrations of the principles of the invention and its practical application and to thereby enable one of ordinary skill in the art to utilize the invention in various embodiments and with various modifications as are suited to the particular use contemplated. All such modifications and variations are within the scope of the invention as determined by the appended claims when interpreted in accordance with the breadth to which they are fairly, legally, and equitably entitled.

What is claimed is:

1. A method for extruding a poly(hydroxyalkanoate)-based material onto a packaging substrate, comprising:

extruding a molten film comprising poly(hydroxyalkanoate) through a die or slot die onto a moving web of the packaging substrate to provide a coated substrate; and

contacting a coated side of the coated substrate with a chill roller to crystallize the molten film on the coated substrate, wherein the chill roller has a temperature ranging from about 30 °C to about 60 °C.

2. The method of claim 1, wherein the chill roller has a temperature ranging from about 30 °C to about 60 °C, and more preferably from about 37 °C to about 55 °C.

3. The method of claim 1, wherein an air gap distance between the die or slot die, and the moving web of packaging material ranges from about 2.54 centimeters to less than about 20 centimeters, and more preferably from about 2.54 centimeters to about 13 centimeters.

4. The method of claim 1, wherein a coating weight of molten film on the coated substrate ranges from about 4 grams/m² to about 200 grams/m².

5. The method of claim 1, wherein a coating thickness of molten film on the coated substrate ranges from about 5 microns to about 200 microns.

6. The method of claim 1, wherein the moving web of packaging substrate has a line speed ranging from 50 to 800 meters per minute.

7. The method of claim 1, wherein the amount of poly(hydroxyalkanoate) in the molten film ranges from about 50 to about 99 weight percent based on a total weight of the molten film.

8. The method of claim 1, further comprising treating the moving web of packaging substrate prior to the extruding step with a pre-treat process selected from flame treating, corona treating, ozone treating, and a combination thereof.

9. The method of claim 8, wherein the moving web of packaging substrate is flame treated to a temperature ranging from about 25 °C to about 60 °C.

10. The method of claim 1, wherein the chill roller comprises a release or non-stick coating including, but not limited to, a polytetrafluoroethylene coating configured to prevent the molten film from sticking to or wrapping around the chill roller.
11. The method of claim 10, wherein the chill roller has a surface feature selected from the group consisting of a smooth surface, a rough surface, a matte surface, and a shiny surface.
12. The method of claim 1, wherein the chill roller has a surface feature selected from the group consisting of a smooth surface, a rough surface, a matte surface, and a shiny surface.
13. The method of claim 1, wherein the extrusion step is carried out at a temperature of less than about 210 °C.
14. The method of claim 1, wherein the extrusion step is carried out using an ultra-low-shear, or low shear screw extruder with a compression ratio below 3.5 and more preferably a compression ratio of less than 3.0.
15. A paperboard web comprising a poly(hydroxyalkanoate) coating made by the method of claim 1.