

CELLULAR POLYMERIC MATERIAL

PRIORITY CLAIM

[0001] This application claims priority under 35 U.S.C. § 119(e) to U.S. Provisional Application Serial No. 61/779,951, filed March 13, 2013, which is expressly incorporated by reference herein.

BACKGROUND

[0002] The present disclosure relates to polymeric materials that can be formed to produce a container, in particular polymeric materials that insulate. More particularly, the present disclosure relates to morphology and crystalline structure of cellular polymeric material that can be transformed into usable articles, such as insulated containers.

SUMMARY

[0003] In one aspect of the present disclosure, there is provided a process for producing an insulative cellular polypropylene-based material comprising:

extruding a formulation through extruder die lips at a die exit angle of 20° to about 60° to produce the insulative cellular polypropylene-based material,

wherein the formulation comprises

- i) a first polymer material comprising at least one high melt strength polypropylene homopolymer,
- ii) a second polymer material comprising at least one polymer selected from the group consisting of crystalline polypropylene homopolymer, impact polypropylene copolymer, and mixtures thereof,
- iii) at least one nucleating agent, and
- iv) at least one slip agent.

[0003A] In another aspect of the present disclosure, there is provided a process for producing an insulative cellular polypropylene-based material comprising:

providing a formulation comprising

- i) a first polymer material comprising at least one high melt strength polypropylene homopolymer,

ii) a second polymer material comprising at least one polymer selected from the group consisting of crystalline polypropylene homopolymer, impact polypropylene copolymer, and mixtures thereof,

iii) at least one nucleating agent, and

iv) at least one slip agent, and

extruding the formulation through an extruder die lip at a die exit angle of about 20° to about 60° to form a sheet of the material without surface indentations of greater than 5 microns when the sheet of the material is curved to form a round article.

[0003B] In a further aspect of the present disclosure, there is provided an insulative cellular polypropylene-based material comprising:

i) a first polymer material comprising at least one high melt strength polypropylene homopolymer, and

ii) a second polymer material comprising at least one polymer selected from the group consisting of crystalline polypropylene homopolymer, impact polypropylene copolymer, and mixtures thereof,

wherein the material has been extruded through an extruder die lip at a die exit angle of about 20° to about 60° so that surface indentations of greater than 5 microns are not present when a sheet of the material is curved to form a round article.

[0003C] Yet a further aspect of the present disclosure provides a process for producing an insulative cellular polypropylene-based material comprising:

providing a formulation comprising

i) a first polymer material comprising at least one high melt strength polypropylene homopolymer,

ii) a second polymer material comprising at least one polymer selected from the group consisting of crystalline polypropylene homopolymer, impact polypropylene copolymer, mixtures thereof,

iii) at least one nucleating agent, and

iv) at least one slip agent, and

extruding the formulation through an extruder nozzle including an inner die lip at an inner die lip angle of about 45° to about 60° and an outer die lip at an angle of about 35° to about 55° to produce the insulative cellular polypropylene-based material without surface indentations of greater than 5 microns when the sheet of the material is curved to form a round article.

[0003D] Also disclosed herein is an insulated container in accordance with the present disclosure, which may be a drink cup or a food-storage cup (*e.g.*), is manufactured from a sheet extrudate or tubular extrudate produced in an extrusion process. In illustrative embodiments, the extrudate is a cellular polymeric material.

[0004] In illustrative embodiments, an insulative container in accordance with the present disclosure is manufactured from a tubular extrudate produced in an extrusion process. In illustrative embodiments, the extrudate is an insulative cellular polypropylene-based material configured to provide resistance to creasing and/or wrinkling during cup convolution or shaping.

[0005] In illustrative embodiments, the cell morphology of an extruded sheet of insulative cellular polypropylene-based material in accordance with the present disclosure is a function of the extrusion angle, which has an effect on the quality of an article, such as an insulative container, formed therewith. In particular, cell morphology is affected by the angle at which a polypropylene-based material in accordance with the present disclosure exits an enclosed die volume through extruder die lips, and is related to a reduction in, if not an elimination of, deep creases and/or wrinkles inside the formed article.

[0006] In illustrative embodiments, the cell morphology of an extruded sheet of insulative cellular polypropylene-based material in accordance with the present disclosure is a function of formulation and process conditions, which conditions have an effect on the quality of

an article, such as an insulative container, formed therewith. In particular, the effects of such conditions on cell density and cell dimensional attributes, and ultimately on crease/wrinkle resistance, results in a wrinkle-resistance prediction model based on power law regression.

[0007] In illustrative embodiments, the cell aspect ratio of an extruded sheet of insulative cellular polypropylene-based material in accordance with the present disclosure has an effect on the wrinkle resistance of that material during mechanical convolution. Parameters such as cell density and aspect ratio ultimately determine control limits that result in a wrinkle-resistance model for the extruded sheet.

[0008] In illustrative embodiments, the machine direction cell aspect ratio of an extruded sheet of insulative cellular polypropylene-based material in accordance with the present disclosure has a greater effect than the cell aspect ratio in the cross-web direction on the wrinkle resistance of that material during mechanical convolution.

[0009] In illustrative embodiments, the orientation of an extruded sheet of insulative cellular polypropylene-based material in accordance with the present disclosure has an effect on the wrinkle resistance of that material during mechanical convolution. In particular, when formed into a circular article, the sheet should be oriented such that the circumference of the circular article represents -45° to $+45^{\circ}$ parallel to the direction of flow for the material of the sheet. The effects of parameters such as sheet orientation in formed circular articles ultimately influence their wrinkle-resistance capability.

[0010] In an illustrative embodiment, cellular polymeric material comprises about 50% to about 100% of a primary resin, 0 to about 50% of a secondary resin, 0 to about 2% of a chemical blowing agent, 0 to about 20% of a physical nucleating agent, 0 to about 20% of a colorant, and about 0 to about 10% of a slip agent.

[0011] In another aspect of the present disclosure, there is provided an insulated container in accordance with the present disclosure is manufactured from a sheet extrudate or tubular extrudate produced in an extrusion process. In illustrative embodiments, the extrudate is a cellular polymeric material and the insulated container is later formed to provide a drink cup, a food-storage, cup, or a container.

[0012] In illustrative embodiments, an insulative container in accordance with the present disclosure is manufactured from a tubular extrudate produced in an extrusion process. In illustrative embodiments, the extrudate in an insulative cellular polypropylene-based material configured to provide resistance to creasing and/or wrinkling during cup convolution or shaping.

[0013] In illustrative embodiments, an extruded tube of insulative cellular polypropylene-based material has an inside-of-extruded-tube (InET) surface/layer and an outside-of-extruded-tube (OET) surface/layer that can be sliced to provide a strip of insulative cellular polypropylene-based material. An extruded tube of insulative cellular polypropylene-based material in accordance with the present disclosure has a surface morphology that includes a beta-crystalline polypropylene phase identified by X-ray wide angle diffraction analysis, which phase is not observable by differential scanning calorimetry (DSC).

[0014] In illustrative embodiments, the surface morphology of an extruded tube of insulative cellular polypropylene-based material in accordance with the present disclosure has a profound effect on the quality of an article, such as an insulative cup, formed therewith. In particular, the specific crystalline structure of the extruded tube surface/layer (InET or OET) facing inside of the insulative cup is directly related to a reduction in, if not an elimination of, visible deep creases and/or wrinkles inside the formed insulative cup.

[0015] In illustrative embodiments, a surface quality exists for a sheet of insulative cellular polypropylene-based material in accordance with the present disclosure that leads to a noticeable crease-free surface in an insulative cup prepared at a specified formulation, and under specified processing and forming conditions. In particular, such surface quality is determined by the properties of the crystalline phases of the polypropylene-based material. More particularly, such surface quality is determined by the relative size and the relative amounts of both the alpha- and beta-crystalline phases present in the polypropylene-based material.

[0016] In illustrative embodiments, a cup-forming process in accordance with the present disclosure provides an insulative cup. The cup-forming process also minimizes wrinkling and/or creasing includes the step of arranging in a cross-web direction (CD) the shape to be cut from an extruded tube of insulative cellular polypropylene-based material with the OET surface/layer facing the inside of the cup.

[0017] In illustrative embodiments, creasing and/or wrinkling of insulative cellular polypropylene-based material having a fixed chemical composition, and made under controlled extrusion process conditions with controlled processing parameters, can essentially be eliminated if die cut parts are oriented in a CD direction. As a result, a cell aspect ratio close to 1 and a coefficient of anisotropy close to 1 is provided.

[0018] In illustrative embodiments, performance of an extruded sheet of insulative cellular polypropylene-based material in accordance with the present disclosure can be a

function of alpha and beta crystal domain size and relative content of beta phase as determined by K-value.

[0019] Additional features of the present disclosure will become apparent to those skilled in the art upon consideration of illustrative embodiments exemplifying the best mode of carrying out the disclosure as presently perceived.

BRIEF DESCRIPTIONS OF THE DRAWINGS

[0020] Fig. 1 is a microscopy image of a 44°-extruded sheet strip from an insulative cellular polypropylene-based material of the present disclosure used to quantify dimensional morphology of cell length and width;

[0021] Fig. 2 is a microscopy image of cell wall measurement for a 44°-extruded sheet strip from an insulative cellular polypropylene-based material of the present disclosure used to quantify dimensional morphology;

[0022] Fig. 3 is a microscopy image of a 90°-extruded sheet strip from an insulative cellular polypropylene-based material of the present disclosure used to quantify dimensional morphology;

[0023] Fig. 4 is an image showing cells with an aspect ratio of about 2.32 and cell density of about 1,216,000 cells/in³, which cells were taken from the CD direction on a convoluted product that demonstrated wrinkle-resistant behavior;

[0024] Fig. 5 is an image showing cells with an aspect ratio of about 3.25 and cell density of about 1,159,000 cells/in³, which cells were taken from the CD direction on a convoluted product that demonstrated micro-creasing and macro-creasing behavior;

[0025] Fig. 6 is an image showing cells with an aspect ratio of about 1.94 and cell density of about 1,631,000 cells/in³, which cells were taken from the MD direction on a convoluted product that demonstrated wrinkle-resistant behavior;

[0026] Fig. 7 is an image showing cells with an aspect ratio of about 3.63 and cell density of about 933,000 cells/in³, which cells were taken from the MD direction on a convoluted product that demonstrated micro-creasing and macro-creasing behavior;

[0027] Fig. 8 is a graph with a power law regression fit of cell density vs. cell length in an x-y plot for insulative cellular polypropylene-based materials of the present disclosure where the power law equation for predicting cell length with respect to cell density is $y = 999,162,715.083x^{-2.613}$ and $R^2 = 0.972$;

[0028] Fig. 9 is a graph with a power law regression fit of cell density vs. cell length in a log-log plot for insulative cellular polypropylene-based materials of the present disclosure where the power law equation for predicting cell length with respect to cell density is $y = 999,162,715.083x^{-2.613}$ and $R^2 = 0.972$;

[0029] Fig. 10 is a graph with a power law regression fit of cell density vs. cell width in an x-y plot for insulative cellular polypropylene-based materials of the present disclosure where the power law equation for predicting cell width with respect to cell density is $y = 287,106,186.479x^{-3.295}$ and $R^2 = 0.974$;

[0030] Fig. 11 is a graph with a power law regression fit of cell density vs. cell width in a log-log plot for insulative cellular polypropylene-based materials of the present disclosure where the power law equation for predicting cell with respect to cell density is $y = 287,106,186.479x^{-3.295}$ and $R^2 = 0.974$;

[0031] Fig. 12 is a graph with a power law regression fit of cell density vs. cell wall thickness in an x-y plot for insulative cellular polypropylene-based materials of the present disclosure where the power law equation for predicting cell wall thickness with respect to cell density is $y = 448,002.648x^{-3.053}$ and $R^2 = 0.973$;

[0032] Fig. 13 is a graph with a power law regression fit of cell density vs. cell wall thickness in a log-log plot for insulative cellular polypropylene-based materials of the present disclosure where the power law equation for predicting cell wall thickness with respect to cell density is $y = 448,002.648x^{-3.053}$ and $R^2 = 0.973$;

[0033] Fig. 14 is a graph with a power law regression fit of cell density vs. cell length in an x-y plot for insulative cellular polypropylene-based materials of the present disclosure where the power law equation for predicting cell length with respect to cell density is $y = 1,243,388,528.484x^{-2.626}$ and $R^2 = 0.945$;

[0034] Fig. 15 is a graph with a power law regression fit of cell density vs. cell width in an x-y plot for insulative cellular polypropylene-based materials of the present disclosure where the power law equation for predicting cell width with respect to cell density is $y = 426,736,129.761x^{-3.417}$ and $R^2 = 0.939$;

[0035] Fig. 16 is an x-y plot of cell density vs. machine direction (MD) cell aspect ratio illustrating the effect of MD cell morphology on creasing;

[0036] Fig. 17 is an x-y plot of cell density vs. cross direction (CD) cell aspect ratio illustrating the effect of CD cell morphology on creasing;

[0037] Fig. 18 is an elevation view of an extrusion nozzle in accordance with the present disclosure with portions enlarged to show an inner die lip angle X and an outer die lip angle Y;

[0038] Fig. 19 illustrates sampling for microscopy and X-Ray analysis for which samples were cut from the side of an insulative cup side wall and analyzed in two perpendicular directions: View A from top to bottom of the cup and view B looking sideways;

[0039] Fig. 20 shows a View A microscopy image of the insulative cup side wall from the cup of Example 5 (with printed film laminated to the foam), where OET is outside of the insulative cup, illustrating that the insulative cup side wall collapsed in compression during cup formation leading to crease formation with crease depth of 0.23 mm;

[0040] Fig. 21 shows a View A microscopy image of the insulative cup side wall from the insulative cup of Example 3 (without laminated printed film and with black marker used to eliminate light reflection for clearer image), where OET is outside of the insulative cup, again illustrating that creasing/deep wrinkles formed on the inside of the insulative cup in the same way as in Fig. 20/Cup 5;

[0041] Fig. 22 shows a differential scanning calorimetry (DSC) graph in which a beta-crystalline phase (*i.e.*, beta-crystallinity) is not detected during a 2nd heat scan for an insulative cellular polypropylene-based material of the present disclosure;

[0042] Fig. 23 shows the wide angle X-ray diffraction (WAXD) pattern for an OET surface sample from the sheet of insulative cellular polypropylene-based material used in Cups 1-5 having a crystalline size of 99 Å and percent crystallinity of 57.8%;

[0043] Fig. 24 shows a comparison of the WAXD patterns for the InET and OET surfaces of the sheet of insulative cellular polypropylene-based material used in Cups 1-5 illustrating the OET with a smaller crystal domain size than the InET and with beta-crystalline phase present; and

[0044] Fig. 25 shows the phase identification for three samples: Top trace – WAXD pattern for Extra talc Sample #1, InET surface showing presence of beta-crystalline phase peak at 16.1°; Middle trace – WAXD pattern for Extra talc Sample #2, InET surface showing presence of beta-crystalline phase peak at 16.1°; Bottom trace – WAXD pattern for Sample B = conventional cellular polypropylene material with no beta-crystalline phase peak present at 16.1°.

DETAILED DESCRIPTION

First aspect of the disclosure

[0045] An unexpected feature of exemplary embodiments of an extruded sheet of insulative cellular polypropylene-based material in accordance with the present disclosure is the ability of the sheet to form a noticeably crease-free and wrinkle-free surface when curved to form a round article, such as an insulative cup. The surface is wrinkle-free even inside the cup, where compression forces typically cause material to crush and/or crease easily, especially for low density material with a large cell aspect ratio. In exemplary embodiments, the surface profile of an extruded sheet of insulative cellular polypropylene-based material as detected by microscopy is such that the depth of the indentations (*i.e.*, creases and/or wrinkles) naturally occurring in the outside and inside of the cup surface when it is subject to extension and compression forces during cup forming may be less than about 100 microns. In one exemplary embodiment, the surface profile may include indentations of less than about 50 microns. In another exemplary embodiment, the surface profile may include indentations of about 5 microns or less. At a depth of about 10 microns and less, micro-wrinkles and/or creases on a cup surface are ordinarily not visible to the naked eye.

[0046] In one exemplary embodiment, an insulative cup formed from a sheet comprising a skin and a strip of insulative cellular polypropylene-based material in accordance with the present disclosure had typical creases (*i.e.*, deep wrinkles) about 200 microns deep extending from the top of the cup to the bottom of the cup. In another exemplary embodiment, an insulative cup formed from a sheet comprising a strip of insulative cellular polypropylene-based material only (without a skin) in accordance with the present disclosure had typical creases about 200 microns deep extending from the top of the cup to the bottom of the cup. Such creases with depths from about 100 microns to about 500 microns are typically formed inside of a cup undergoing compression. Creases and deep wrinkles may present a problem of unsatisfactory surface quality making cups with such surface features unusable or undesirable. Creases may form in instances where sheets include a skin or exclude a skin.

[0047] It was unexpectedly found that the cell morphology of an extruded sheet of insulative cellular polypropylene-based material in accordance with the present disclosure has an effect on the quality of the formed article, such as an insulative cup. The effects of cell morphology on wrinkle resistance in insulative cellular polypropylene-based material can be illustrated through examining the effect of varying extruder die lips angle. In exemplary embodiments, the angle at which insulative cellular polypropylene-based material in accordance

with the present disclosure exits an enclosed volume may affect the material's wrinkle resistance. It was found that for a specified formulation of insulative cellular polypropylene-based material and specified cup forming conditions, different die exit angles lead to noticeably different levels of creasing and/or wrinkling in article surfaces during extruded sheet convolution. The two geometric exit angles selected for examination in the present disclosure are those commonly used in polyethylene foam production, *i.e.*, an exit angle of 90°, and in polystyrene foam production, *i.e.*, an exit angle of 44° (*see*, Example 1).

[0048] In exemplary embodiments, insulative cellular polypropylene-based material in accordance with the present disclosure may be extruded as sheet. Microscopy images show that distinct cell morphology exists, *i.e.*, cell structure distinctions, within such an extruded sheet when one sheet is produced with a higher curvature die exit angle and the other with a lower curvature die exit angle. When the resulting sheets are cut in the cross direction and machine direction and examined under a microscope, the difference in cell morphology between the two sheets can be detected.

[0049] Direct evidence of polymer cell structure is provided by microscopy studies. There is a close relationship between the regularity of molecular structure and malleability. Cell morphology describes polymer cell density, cell structure, cell wall thickness, cell shape, and cell size distribution of cells. Polymer cell structures may have the same general shape and appearance, being composed predominantly of ovular cells, and the same lognormal cell distribution, but possess a different cell aspect ratio and cell wall thickness. Illustratively, cell aspect ratio is the ratio between lengths of the ovular polymer cells to widths of the ovular polymer cells. Illustratively, cell wall thickness is the solid polymeric distance between individual polymer cells.

[0050] In one exemplary embodiment, an extruded sheet of insulative cellular polypropylene-based material in accordance with the present disclosure may exit from an enclosed die volume at an angle of 90°. In another exemplary embodiment, an extruded sheet of insulative cellular polypropylene-based material may exit from an enclosed die volume at an angle of 44°. Illustratively, an extruded sheet of insulative cellular polypropylene-based material may exit from an enclosed die volume at an angle between 44° and 90°. Two such sheets, one produced at an exit angle of 44° and the other at an exit angle of 90°, can be prepared as strips either in the machine direction or in the cross direction and analyzed with digital microscopy. Cell density, cell distribution, cell shape, cell aspect ratio, and cell wall thickness of an extruded sheet can be held constant when extrusion parameters such as recipe, temperature, and cooling

rate are the same. In the present disclosure, formation of wrinkled material was found to occur when the exit angle of curvature increased from 44° to 90° (*see*, Example 1, Figs. 1-3). Without wishing to be bound by theory, one plausible explanation may be that cell density and dimensional morphology are a function of enclosed die volume exit angle, *i.e.*, cell density and dimensional morphology may be altered upon exit from different enclosed die volume exit angles, thereby creating wrinkled material. Because production of insulative cellular polypropylene-based material with CO₂ as a blowing agent is still in industrial infancy and development, the present disclosure provides a basis for new process development involving the use of die angle geometries and their effect on cell morphology.

[0051] The disclosure herein provides methods of producing an insulative cellular material. In an embodiment, the insulative cellular material is polypropylene based. In an embodiment, the insulative cellular material is wrinkle- and/or crease-resistant. In an embodiment, a method of producing an insulative cellular material includes extruding a formulation as disclosed herein through an extrude die lips at an exit angle from 0° to about 60°. In an embodiment, the formulation is extruded through die lips angle is 0° to about 10°, about 10° to about 20°, about 20° to about 30°, about 30° to about 40°, about 40° to about 50°, about 50° to about 60°, about 40° to about 45°, 0° to about 20°, 0° to about 30°, 0° to about 40°, 0° to about 50°, about 10° to about 60°, about 10° to about 50°, about 10° to about 40°, about 10° to about 30°, about 20° to about 60°, about 20° to about 50°, about 20° to about 40°, about 30° to about 60°, about 30° to about 50°, or about 40° to about 60°. An embodiment includes the method wherein the die exit angle can be about 10°, 20°, 30°, 40°, 41°, 42°, 43°, 44°, 45°, 46°, 47°, 48°, 49°, 50°, or 60°.

[0052] In an embodiment of a method of producing an insulative cellular material, wherein the formulation comprises i) a first polymer material comprising at least one high melt strength polypropylene homopolymer, and ii) a second polymer material comprising at least one polymer selected from the group consisting of crystalline polypropylene homopolymer, impact polypropylene copolymer, and mixtures thereof. In an embodiment, the formulation further comprises at least one nucleating agent. In an embodiment, the formulation further comprises at least one slip agent. In an embodiment of a method of producing an insulative cellular material, cell dimensional attributes are according to $y = Ax^K$, wherein either x or y is cell density of the insulative cellular polypropylene-based material and the non-cell density variable is cell length, cell width, or cell wall thickness of the insulative cellular polypropylene-based material.

[0053] It was unexpectedly found that cell morphology, especially cell density, of an extruded sheet of insulative cellular polypropylene-based material in accordance with the present disclosure has an effect on the quality of the formed article, such as a cup, formed therewith. The effects of cell density and dimensional attributes on wrinkle resistance in insulative cellular polypropylene-based material can be illustrated through examining cell morphology data from different formulations and process conditions, thus creating a wrinkle-resistance prediction model based on power law regression.

[0054] In exemplary embodiments, the cell density of insulative cellular polypropylene-based material in accordance with the present disclosure may affect the material's resistance to wrinkling. In other exemplary embodiments, the total cell number of insulative cellular polypropylene-based material may affect the material's wrinkle resistance to wrinkling. In other exemplary embodiments, the cell aspect ratio in the machine direction, *i.e.*, the direction parallel to the flow of insulative cellular polypropylene-based material, may affect the material's resistance to wrinkling. In other exemplary embodiments, the cell aspect ratio in the cross direction, *i.e.*, the direction perpendicular to the flow of insulative cellular polypropylene-based material, may affect the material's resistance to wrinkling. In other exemplary embodiments, the overall cell length of insulative cellular polypropylene-based material may affect the material's resistance to wrinkling. In other exemplary embodiments, the overall cell thickness of insulative cellular polypropylene-based material may affect the material's resistance to wrinkling. In other exemplary embodiments, the cell length of insulative cellular polypropylene-based material may affect the material's resistance to wrinkling. In other exemplary embodiments, the cell width of insulative cellular polypropylene-based material may affect the material's resistance to wrinkling. In other exemplary embodiments, the cell wall thickness of insulative cellular polypropylene-based material may affect the material's resistance to wrinkling. In other exemplary embodiments, cell dimensional attributes may follow a power law that is independent of formula and processing conditions (*see*, Example 2, Figs. 8-15).

[0055] Accordingly, although production of insulative cellular polypropylene-based material with CO₂ as a blowing agent is still in industrial infancy and development, the present disclosure also provides process know how and a basis for predicting wrinkle resistance in insulative cellular polypropylene-based material that is independent of material formula and processing conditions.

[0056] The insulative cellular polypropylene-based material of the present disclosure satisfies a long-felt need for a material that can be formed into an article, such as an insulative

cup, that includes the features of wrinkle-resistance and crease-resistance as described herein, as well as many, if not all, of the features of insulative performance, recyclability, puncture resistance, frangibility resistance, and microwavability, which features are described in U.S. Patent Application Serial Nos. 13/491,007 and 13/491,327 both of which are incorporated herein by reference in their entirety. Others have failed to provide a material that achieves combinations of these features as reflected in the appended claims.

[0057] Nucleating agent means a chemical or physical material that provides sites for cells to form in a molten formulation mixture. Nucleating agents may include chemical nucleating agents and physical nucleating agents. The nucleating agent may be blended with the formulation that is introduced into the hopper of the extruder. Alternatively, the nucleating agent may be added to the molten resin mixture in the extruder.

[0058] Suitable physical nucleating agents have desirable particle size, aspect ratio, and top-cut properties. Examples include, but are not limited to, talc, CaCO_3 , mica, and mixtures of at least two of the foregoing. One representative example is Heritage Plastics HT6000 Linear Low Density Polyethylene (LLDPE) Based Talc Concentrate.

[0059] Suitable chemical nucleating agents decompose to create cells in the molten formulation when a chemical reaction temperature is reached. These small cells act as nucleation sites for larger cell growth from a physical or other type of blowing agent. In one example, the chemical nucleating agent is citric acid or a citric acid-based material. One representative example is HYDROCEROL™ CF-40E (available from Clariant Corporation), which contains citric acid and a crystal nucleating agent.

[0060] A “blowing agent” refers to a physical or a chemical blowing agent (or combination of materials) that acts to expand nucleation sites. Blowing agents may include only chemical blowing agents, only physical blowing agents, combinations thereof, or several types of chemical and physical blowing agents. The blowing agent acts to reduce density by forming cells in the molten formulation at the nucleation sites. The blowing agent may be added to the molten resin mixture in the extruder.

[0061] Chemical blowing agents are materials that degrade or react to produce a gas. Chemical blowing agents may be endothermic or exothermic. Chemical blowing agents typically degrade at a certain temperature to decompose and release gas. One example of a chemical blowing agent is citric acid or citric-based material. One representative example is HYDROCEROL™ CF-40E (available from Clariant Corporation), which contains citric acid and a crystal nucleating agent. Here, the citric acid decomposes at the appropriate temperature

in the molten formulation and forms a gas which migrates toward the nucleation sites and grows cells in the molten formulation. If sufficient chemical blowing agent is present, the chemical blowing agent may act as both the nucleating agent and the blowing agent.

[0062] In another example, chemical blowing agents may be selected from the group consisting of azodicarbonamide; azodiisobutyro-nitrile; benzenesulfonylhydrazide; 4,4-oxybenzene sulfonylsemicarbazide; p-toluene sulfonyl semi-carbazide; barium azodicarboxylate; N,N'-dimethyl-N,N'-dinitrosoterephthalamide; trihydrazino triazine; methane; ethane; propane; n-butane; isobutane; n-pentane; isopentane; neopentane; methyl fluoride; perfluoromethane; ethyl fluoride; 1,1-difluoroethane; 1,1,1-trifluoroethane; 1,1,1,2-tetrafluoroethane; pentafluoroethane; perfluoroethane; 2,2-difluoropropane; 1,1,1-trifluoropropane; perfluoropropane; perfluorobutane; perfluorocyclobutane; methyl chloride; methylene chloride; ethyl chloride; 1,1,1-trichloroethane; 1,1-dichloro-1-fluoroethane; 1-chloro-1,1-difluoroethane; 1,1-dichloro-2,2,2-trifluoroethane; 1-chloro-1,2,2,2-tetrafluoroethane; trichloromonofluoromethane; dichlorodifluoromethane; trichlorotrifluoroethane; dichlorotetrafluoroethane; chloroheptafluoropropane; dichlorohexafluoropropane; methanol; ethanol; n-propanol; isopropanol; sodium bicarbonate; sodium carbonate; ammonium bicarbonate; ammonium carbonate; ammonium nitrite; N,N'-dimethyl-N,N'-dinitrosoterephthalamide; N,N'-dinitrosopentamethylene tetramine; azodicarbonamide; azobisisobutyronitrile; azocyclohexylnitrile; azodiaminobenzene; bariumazodicarboxylate; benzene sulfonyl hydrazide; toluene sulfonyl hydrazide; p,p'-oxybis(benzene sulfonyl hydrazide); diphenyl sulfone-3,3'-disulfonyl hydrazide; calcium azide; 4,4'-diphenyl disulfonyl azide; p-toluene sulfonyl azide; and combinations thereof.

[0063] In an illustrative embodiment, a nucleating agent can be about 0.1% to about 20% (w/w), about 0.25% to about 20%, about 0.5% to about 20%, about 0.75% to about 20%, about 1% to about 20%, about 1.5% to about 20%, about 2% to about 20%, about 2.5% to about 20%, about 3% to about 20%, about 3% to about 20%, about 4% to about 20%, about 4.5% to about 20%, about 5% to about 20%, about 0.1% to about 10%, about 0.25% to about 10%, about 0.5% to about 10%, about 0.75% to about 10%, about 1.0% to about 10%, about 1.5% to about 10%, about 1.0% to about 10%, about 2.0% to about 10%, about 2.5% to about 10%, about 3.0% to about 10%, about 3.5% to about 10%, about 4.0% to about 10%, about 4.5% to about 10%, about 5.0% to about 10%, about 0.1% to about 5%, about 0.25% to about 5%, about 0.5% to about 5%, about 0.75% to about 5%, about 1% to about 5%, about 1.5% to about 5%, about 1% to about 5%, about 2% to about 5%, about 2.5% to about 5%, about 3% to about 5%, about 3.5%

to about 5%, or about 4% to about 5%, or about 4.5% to about 5%. In an embodiment, a nucleating agent can be about 0.5%, about 1%, about 1.5%, about 2%, about 2.5%, about 3%, about 4%, or about 5% (w/w). In an embodiment, the polymeric material lacks a nucleating agent. In an embodiment, the polymeric material lacks talc.

[0064] In an illustrative embodiment, a chemical blowing agent can be 0 to about 5% (w/w), about 0.1% to about 5% (w/w), about 0.25% to about 5%, about 0.5% to about 5%, about 0.75% to about 5%, about 1% to about 5%, about 1.5% to about 5%, about 2% to about 5%, about 3% to about 5%, about 4% to about 5%, 0 to about 4% (w/w), about 0.1% to about 4% (w/w), about 0.25% to about 4%, about 0.5% to about 4%, about 0.75% to about 4%, about 1% to about 4%, about 1.5% to about 4%, about 2% to about 4%, about 3% to about 4%, 0 to about 3% (w/w), about 0.1% to about 3% (w/w), about 0.25% to about 3%, about 0.5% to about 3%, about 0.75% to about 3%, about 1% to about 3%, about 1.5% to about 3%, about 2% to about 3%, 0 to about 2%, about 0.1% to about 2% (w/w), about 0.25% to about 2%, about 0.5% to about 2%, about 0.75% to about 2%, about 1% to about 2%, about 1.5% to about 2%, 0 to about 1%, about 0.1% to about 1%, about 0.5% to about 1%, or about 0.75% to about 1%. In an illustrative embodiment, a chemical blowing agent can be about 0.1%, 0.5%, 0.75%, 1%, 1.5% or about 2%. In one aspect of the present disclosure, where a chemical blowing agent is used, the chemical blowing agent may be introduced into the material formulation that is added to the hopper.

[0065] One example of a physical blowing agent is nitrogen (N_2). The N_2 is pumped into the molten formulation via a port in the extruder as a supercritical fluid. The molten material with the N_2 in suspension then exits the extruder via a die where a pressure drop occurs. As the pressure drop happens, N_2 moves out of suspension toward the nucleation sites where cells grow. Excess gas blows off after extrusion with the remaining gas trapped in the cells formed in the extrudate. Other suitable examples of physical blowing agents include, but are not limited to, carbon dioxide (CO_2), helium, argon, air, pentane, butane, or other alkane mixtures of the foregoing and the like.

[0066] In one aspect of the present disclosure, at least one slip agent may be incorporated into the formulation to aid in increasing production rates. Slip agent (also known as a process aid) is a term used to describe a general class of materials which are added to the formulation and provide surface lubrication to the polymer during and after conversion. Slip agents may also reduce or eliminate die drool. Representative examples of slip agent materials include amides of fats or fatty acids, such as, but not limited to, erucamide and oleamide. In one

exemplary aspect, amides from oleyl (single unsaturated C-18) through erucyl (C-22 single unsaturated) may be used. Other representative examples of slip agent materials include low molecular weight amides and fluoroelastomers. Combinations of two or more slip agents can be used. Slip agents may be provided in a master batch pellet form and blended with the resin formulation. One example of a suitable slip agent is Ampacet 102823 Process Aid PE MB LLDPE.

[0067] In an embodiment, a slip agent can be about 0% to about 10% (w/w), about 0.5% to about 10% (w/w), about 1% to about 10% (w/w), about 2% to about 10% (w/w), about 3% to about 10% (w/w), about 4% to about 10% (w/w), about 5% to about 10% (w/w), about 6% to about 10% (w/w), about 7% to about 10% (w/w), about 8% to about 10% (w/w), about 9% to about 10% (w/w), about 0% to about 9% (w/w), about 0.5% to about 9% (w/w), about 1% to about 9% (w/w), about 2% to about 9% (w/w), about 3% to about 9% (w/w), about 4% to about 9% (w/w), about 5% to about 9% (w/w), about 6% to about 9% (w/w), about 7% to about 9% (w/w), about 8% to about 9% (w/w), about 0% to about 8% (w/w), about 0.5% to about 8% (w/w), about 1% to about 8% (w/w), about 2% to about 8% (w/w), about 3% to about 8% (w/w), about 4% to about 8% (w/w), about 5% to about 8% (w/w), about 6% to about 8% (w/w), about 7% to about 8% (w/w), about 0% to about 7% (w/w), about 0.5% to about 7% (w/w), about 1% to about 7% (w/w), about 2% to about 7% (w/w), about 3% to about 7% (w/w), about 4% to about 7% (w/w), about 5% to about 7% (w/w), about 6% to about 7% (w/w), about 0% to about 6% (w/w), about 0.5% to about 6% (w/w), about 1% to about 6% (w/w), about 2% to about 6% (w/w), about 3% to about 6% (w/w), about 4% to about 6% (w/w), about 5% to about 6% (w/w), about 0% to about 5% (w/w), about 0.5% to about 5% (w/w), about 1% to about 5% (w/w), about 2% to about 5% (w/w), about 3% to about 5% (w/w), about 4% to about 5% (w/w), about 0% to about 4% (w/w), about 0.5% to about 4% (w/w), about 1% to about 4% (w/w), about 2% to about 4% (w/w), about 3% to about 4% (w/w), about 0% to about 3% (w/w), about 0.5% to about 3% (w/w), about 1% to about 3% (w/w), about 2% to about 3% (w/w), about 0% to about 2% (w/w), about 0.5% to about 2% (w/w), about 1% to about 2% (w/w), about 0% to about 1% (w/w), or about 0.5% to about 1% (w/w). In an embodiment, a slip agent can be about 0.5%, about 1%, about 2%, about 3%, about 4%, about 5%, about 6%, about 7%, about 8%, about 9%, or about 10% (w/w). In an embodiment, the formulation lacks a slip agent.

[0068] In an embodiment, a colorant can be about 0% to about 20% (w/w), about 0% to about 15% (w/w), about 0% to about 10% (w/w), about 0% to about 5% (w/w), about 0% to about 4% (w/w), about 0.1% to about 4%, about 0.25% to about 4%, about 0.5% to about 4%,

about 0.75% to about 4%, about 1.0% to about 4%, about 1.5% to about 4%, about 2.0% to about 4%, about 2.5% to about 4%, about 3% to about 4%, about 0% to about 3.0%, about 0% to about 2.5%, about 0% to about 2.25%, about 0% to about 2.0%, about 0% to about 1.5%, about 0% to about 1.0%, about 0% to about 0.5%, about 0.1% to about 3.5%, about 0.1% to about 3.0%, about 0.1% to about 2.5%, about 0.1% to about 2.0%, about 0.1% to about 1.5%, about 0.1% to about 1.0%, about 1% to about 5%, about 1% to about 10%, about 1% to about 15%, about 1% to about 20%, or about 0.1% to about 0.5%. In an embodiment, a formulation lacks a colorant.

[0069] In one exemplary embodiment, a formulation used to produce the cellular polymeric material includes at least one polymeric material. The polymeric material may include one or more base resins. In one example, the base resin is polypropylene. In an illustrative embodiment, a base resin can include Borealis WB140 HMS polypropylene homopolymer. In another illustrative embodiment, a base resin can include Braskem F020HC polypropylene homopolymer. In an embodiment, a base resin can include both Borealis WB140 HMS polypropylene homopolymer and Braskem F020HC polypropylene homopolymer.

[0070] In embodiments with more than one polypropylene copolymer base resin, different polypropylene copolymers can be used depending on the attributes desired in the formulation. Depending on the desired characteristics, the ratio of two polypropylene resins may be varied, e.g., 10%/90%, 20%/80%, 25%/75%, 30%/70%, 35%/65%, 40%/60%, 45%/55%, 50%/50%, etc. In an embodiment, a formulation includes three polypropylene resins in the base resin. Again, depending on the desired characteristics, the percentage of three polypropylene resins can be varied, 33%/33%/33%, 30%/30%/40%, 25%/25%/50%, etc.

[0071] In illustrative embodiments, a polymeric material includes a primary base resin. In illustrative embodiments, a base resin may polypropylene. In illustrative embodiments, an insulative cellular non-aromatic polymeric material comprises a polypropylene base resin having a high melt strength, a polypropylene copolymer or homopolymer (or both). In an embodiment, a formulation of the polymeric material comprises about 50 wt% to about 100 wt%, about 70 wt% to about 100 wt%, about 50 wt% to about 99 wt%, 50 wt% to about 95 wt%, about 50 wt% to about 85 wt%, about 55 wt% to about 85 wt%, about 80 wt% to about 85 wt%, about 80 wt% to about 90 wt%, about 80 wt% to about 91 wt%, about 80 wt% to about 92 wt%, about 80 wt% to about 93 wt%, about 80 wt% to about 94 wt%, about 80 wt% to about 95 wt%, about 80 wt% to about 96 wt%, about 80 wt% to about 97 wt%, about 80 wt% to about 98 wt%, about 80 wt% to about 99 wt%, about 85 wt% to about 90 wt%, or about 85 wt% to about 95 wt% of the

primary base resin. In an embodiment, a colorant can be about 80%, 81%, 82%, 83%, 84%, 85%, 86%, 87%, 88%, 89%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or 100%,.

[0072] As defined hereinbefore, any suitable primary base resin may be used. One illustrative example of a suitable polypropylene base resin is DAPLOY™ WB140 homopolymer (available from Borealis A/S) which is a high melt strength structural isomeric modified polypropylene homopolymer.

[0073] In illustrative embodiments, a polymeric material includes a secondary resin, wherein the secondary resin can be a polypropylene copolymer or homopolymer (or both). In another embodiment, a secondary resin can be about 0 wt% to about 50 wt%, about 0 wt% to about 30 wt%, about 0 wt% to about 25 wt%, about 0 wt% to about 20 wt%, about 0 wt% to about 15 wt%, about 10 wt% to about 50 wt%, about 10 wt% to about 40 wt%, about 10 wt% to about 30 wt%, about 10 wt% to about 25 wt%, about 10 wt% to about 20 wt%, or about 10 wt% to about 15 wt% of a secondary resin. In an embodiment, a polymeric material includes about 0 wt%, about 10 wt%, about 15 wt%, about 20 wt%, about 25 wt%, or about 30 wt%. In an embodiment, a polymeric material does not have a secondary resin. In a particular embodiment, a secondary resin can be a high crystalline polypropylene homopolymer, such as F020HC (available from Braskem) or PP 527K (available from Sabic). In an embodiment, a polymeric material lacks a secondary resin.

[0074] The term die exit angle will be understood to denote the angle subtended by the central axis of the torpedo mandrel and the outer surface of the torpedo mandrel adjacent the exit lip of an extrusion apparatus. Such an angle may be referred to as an inner lip angle, and is commonly understood to denote angle X in Fig. 18. Suitably, the die exit angle is an angle as defined in any of the following numbered paragraphs 1-15:

- 1) 1-60°
- 2) 10-60°
- 3) 20-60°
- 4) 30-60°
- 5) 30-58°
- 6) 32-58°
- 7) 35-58°
- 8) 35-56°
- 9) 37-54°

10) 40-54°

11) 40-52°

12) 40-50°

13) 40-48°

14) 42-48°

15) 42-46°

[0075] In particular embodiments of the disclosure, the die exit angle may be formed by an inner lip angle identified as X in Fig. 18 and an outer lip angle identified as Y in the in Fig. 18. Outer lip angle Y is the angle subtended by the lip of the extrusion apparatus and the central axis of a torpedo mandrel. Inner lip angle X is the angle subtended by the central axis of the torpedo mandrel and the outer surface of the torpedo mandrel adjacent the lip of the extrusion apparatus as shown in Fig. 18. Suitably, angles X and Y are as defined in any of the following numbered paragraphs 16-22:

16) X is 45-60° and Y is 35-55°

17) X is 47-58° and Y is 37-50°

18) X is 47-56° and Y is 37-48°

19) X is 47-54° and Y is 39-46°

20) X is 48-54° and Y is 40-45°

21) X is 49° and Y is 41°

22) X is 53° and Y is 41°

[0076] In an embodiment, the process comprises extruding a formulation at any of the angles defined in numbered paragraphs 1-22 above, wherein the formulation comprises:

50 – 100 wt% of a primary base resin

0 – 50 wt% of a secondary resin

0 – 5 wt% of a chemical blowing agent

0.1 – 20 wt% of a nucleating agent

0 – 20 wt% of a colorant

0 – 10 wt% of a slip agent

[0077] In an embodiment, the process comprises extruding a formulation at any of the angles defined in numbered paragraphs 1-20 above, wherein the formulation comprises:

- 50 – 100 wt% of a primary base resin
- 0 – 50 wt% of a secondary resin
- 0 – 2 wt% of a chemical blowing agent
- 0 – 20 wt% of a physical nucleating agent
- 0 – 20 wt% of a colorant
- 0 – 10 wt% of a slip agent

[0078] In an embodiment, the process comprises extruding a formulation at any of the angles defined in numbered paragraphs 1-20 above, wherein the formulation comprises:

- 75 – 85 wt% of a primary base resin
- 10 – 20 wt% of a secondary resin
- 0 – 0.1 wt% of a chemical blowing agent
- 0.1 – 3 wt% of a nucleating agent
- 0 – 2 wt% of a colorant
- 0 – 4 wt% of a slip agent

[0079] In an embodiment, the process comprises extruding a formulation at any of the angles defined in numbered paragraphs 1-20 above, wherein the formulation comprises:

- 50 – 99.65 wt% of the primary base resin
- 0 – 50 wt% of the secondary resin
- 0 – 10 wt% of the slip agent
- 0 – 10 wt% of the colorant
- 0.35– 1.5 wt% of nucleating agent

[0080] In an embodiment, the process comprises extruding a formulation at any of the angles defined in numbered paragraphs 1-20 above, wherein the formulation comprises:

- 50 – 95 wt% of the primary base resin
- 0 – 50 wt% of the secondary resin
- 0 – 10 wt% of the slip agent
- 0 – 10 wt% of the colorant
- 0.4 – 1.2 wt% of nucleating agent

[0081] In an embodiment, the process comprises extruding a formulation at any of the angles defined in numbered paragraphs 1-20 above, wherein the formulation comprises:

- 55 – 85 wt% of the primary base resin

0 – 50 wt% of the secondary resin
0 – 10 wt% of the slip agent
0 – 10 wt% of the colorant
0.45 – 1.25 wt% of nucleating agent

[0082] In an embodiment, the process comprises extruding a formulation at any of the angles defined in numbered paragraphs 1-20 above, wherein the formulation comprises:

50 – 99.69 wt% of the primary base resin
0 – 50 wt% of the secondary resin
0 – 10 wt% of the slip agent
0 – 10 wt% of the colorant
0.01 – 1.5 wt% of the primary nucleating agent
0.3 – 1.7 wt% of the secondary nucleating agent

[0083] In an embodiment, the process comprises extruding a formulation at any of the angles defined in numbered paragraphs 1-20 above, wherein the formulation comprises:

50 – 95 wt% of the primary base resin
0 – 50 wt% of the secondary resin
0 – 10 wt% of the slip agent
0 – 10 wt% of the colorant
0.02 – 1.0 wt% of the primary nucleating agent
0.4 – 1.5 wt% of the secondary nucleating agent

[0084] In an embodiment, the process comprises extruding a formulation at any of the angles defined in numbered paragraphs 1-20 above, wherein the formulation comprises:

55 – 85 wt% of the primary base resin
0 – 50 wt% of the secondary resin
0 – 10 wt% of the slip agent
0 – 10 wt% of the colorant
0.03 – 0.7 wt% of the primary nucleating agent
0.45 – 1.25 wt% of the secondary nucleating agent

[0085] In an embodiment, the process comprises extruding a formulation at any of the angles defined in numbered paragraphs 1-20 above, wherein the formulation comprises:

78 – 83 wt% of a primary base resin
14 – 16 wt% of a secondary resin
0 – 0.05 wt% of a chemical blowing agent

0.25 – 2 wt% of a nucleating agent

1 – 2 wt% of a colorant

1.5 – 3.5 wt% of a slip agent

[0086] In the preceding embodiments, the primary base resin may comprise a polypropylene. Suitably, the primary base resin comprises at least one of Borealis WB140 HMS polypropylene homopolymer and Braskem F020HC polypropylene homopolymer. More suitably, the primary base resin is Borealis WB140 HMS polypropylene homopolymer.

[0087] In the preceding embodiments, the secondary resin may comprise at least one polypropylene copolymer or polypropylene homopolymer. Suitably, the secondary resin comprises at least one of Braskem F020HC polypropylene homopolymer and PP 527K (available from Sabic). More suitably, the secondary resin is Braskem F020HC polypropylene homopolymer.

[0088] In the preceding embodiments, the chemical blowing agent may comprise citric acid, or a citric acid-based material. Suitably the chemical blowing agent is Hydrocerol™ CF-40E (available from Clariant Corporation).

[0089] In the preceding embodiments, the nucleating agent may comprise talc, CaCO₃, mica and mixtures thereof. Suitably, the nucleating agent is one or more of HT4HP talc (available from Heritage Plastics) and HT6000 Linear Low Density Polyethylene (LLDPE) (available from Heritage Plastics) and Techmer PM PPM 16466 Silica. More suitably, the nucleating agent is HT4HP talc (available from Heritage Plastics) or Techmer PM PPM 16466 Silica. A primary nucleating agent may be defined as a chemical blowing agent or chemical foaming agent, itself comprising a nucleating agent. In a particular embodiment, a primary nucleating agent is Hydrocerol™ CF-40E™ (available from Clariant Corporation). In a particular embodiment, a secondary nucleating agent is selected from HPR-803i fibers (available from Milliken) or talc

[0090] In the preceding embodiments, the colorant may comprise at least one of Colortech 11933-19 TiO₂ PP and Cell Stabilizer. Suitably, the colorant is Colortech 11933-19 TiO₂ PP.

[0091] In the preceding embodiments, the slip agent may comprise one or more amides of fats or fatty acids, such as erucamide and oleamide. The slip agent may also comprise one or more low molecular weight amides and fluoroelastomers. Suitably, the slip agent is Ampacet 102823 Process Aid PE MB LLDPE.

[0092] The method of any of the preceding embodiments may also comprise adding CO₂ to the formulation prior to extrusion at a rate of 1-4 lbs/hr. Suitably, the CO₂ is added at a rate of 2-3 lbs/hr. More suitably, the CO₂ is added at a rate of 2.2-2.8 lbs/hr. Such practice may also be referred to as adding a physical blowing agent.

Second aspect of the disclosure

[0093] An insulated container in accordance with the present disclosure is manufactured from a sheet of insulative cellular non-aromatic polymeric material produced in an extrusion process. The sheet of insulative cellular non-aromatic polymeric material is then formed to provide an insulative cup or container which may be used as a drink cup or a food-storage cup as suggested in Fig. 19. The insulative cellular non-aromatic polymeric material of the present disclosure is an insulative cellular polypropylene-based material that is configured to provide resistance to creasing and/or wrinkling during cup convolution, shaping, or forming. Figs. 20-25 are a series of views showing support for various theories explaining how material of the present disclosure is able to resist creasing and/or wrinkling during cup convoluting, shaping, and forming.

[0094] In exemplary embodiments, a tube of extruded insulative cellular polypropylene-based material in accordance with the present disclosure has two surfaces that are formed under different cooling conditions when the material is extruded. One surface, referred to herein as the outside-of-extruded-tube (OET) surface, is in contact with air, and does not have physical barriers restricting expansion. The OET surface is cooled by blowing compressed air at cooling rate equal or higher than 12°F per second. The surface on the opposite side of an extruded tube of insulative cellular polypropylene-based material is referred to herein as the inside-of-extruded-tube (InET) surface. The InET surface is formed when the extruded tube is drawn in the web or machine direction on a metal cooling surface of a torpedo mandrel that is physically restricting the inside of the extruded tube and is cooled by combination of water and compressed air at a cooling rate below 10°F per second. In exemplary embodiments, the cooling water temperature is about 135°F (57.22 °C). In other exemplary embodiments, the cooling air temperature is about 85°F (29.44 °C). As a result of different cooling mechanisms and/or rates, the OET and InET surfaces have different surface characteristics. Cooling rate and method

affects the crystallization process of polypropylene thereby altering its morphology (size of crystal domains) and topography (surface profile).

[0095] An unexpected feature of exemplary embodiments of an extruded sheet of insulative cellular polypropylene-based material as described herein is the ability of the sheet to form a noticeably crease-free and wrinkle-free surface when curved to form a round article, such as an insulative cup. The surface is wrinkle-free even inside the cup, where compression forces typically cause material to crush and/or crease easily, especially for low density material with large cell size. In exemplary embodiments, the surface profile of an extruded sheet of insulative cellular polypropylene-based material as detected by microscopy is such that the depth of the indentations (*i.e.*, creases and/or wrinkles) naturally occurring in the outside and inside of the cup surface when it is subject to extension and compression forces during cup forming may be less than about 100 microns. In one exemplary embodiment, the surface profile may be less than about 50 microns. In one exemplary embodiment, the surface profile may be about 5 microns or less. At a depth of about 10 microns and less, the micro-wrinkles on a cup surface are ordinarily not visible to the naked eye.

[0096] In one exemplary embodiment, an insulative cup formed from a sheet comprising a skin and a strip of insulative cellular polypropylene-based material had typical creases (*i.e.*, deep wrinkles) about 200 microns deep extending from a top of the cup to a bottom of the cup. In one exemplary embodiment, an insulative cup formed from a sheet comprising a strip of insulative cellular polypropylene-based material only (without a skin) had typical creases about 200 microns deep extending from a top of the cup to a bottom of the cup. Such creases with depths from about 100 microns to about 500 microns are typically formed when InET is facing inside of the cup in a compression mode. Creases and deep wrinkles may present a problem of unsatisfactory surface quality making final cups unusable or undesirable. Creases may form in instances where sheets include a skin or exclude a skin.

[0097] In exemplary embodiments, the insulative cellular polypropylene-based material may be extruded as strip. However microscopy images show that two distinct layers exist within the extruded strip, namely, a dull OET layer and shiny InET layer. The difference between the two layers is in reflectance of the surface due to the difference in crystal domain size. If a black marker is used to color the surface examined by microscopy, reflectance is eliminated and the difference between the two surfaces may be minimal or undetectable. In one exemplary embodiment, a sample strip of insulative cellular polypropylene-based material was prepared without any skin. Black marker was used to eliminate any difference in reflectance

between the layers. Images showed that the cell size and cell distribution was the same throughout the strip thickness.

[0098] Differential scanning calorimetry (DSC) analysis conducted on a TA Instruments DSC 2910 in nitrogen atmosphere showed that with an increase in cooling rate, the crystallization temperature and crystallinity degree decreased for the insulative cellular polypropylene-based polymer matrix of the strip, as shown below in Table A.

Table A

Crystallization of polymer matrix					
Crystallization temp, in °C			Crystallinity degree, in %		
Slower cooling 5°C/min	10°C/min	Faster cooling 15°C/min	Slower cooling 5°C/min	10°C/min	Faster cooling 15°C/min
135.3	131.5	129.0	49.2	48.2	47.4

Melting (2 nd heat) of polymer matrix (heating rate 10 °C/min) after crystallization					
Melting temp, °C			Crystallinity degree, %		
Slower cooling 5°C/min	10°C/min	Faster cooling 15°C/min	Slower cooling 5°C/min	10°C/min	Faster cooling 15°C/min
162.3	162.1	161.8	48.7	47.2	46.9

[0099] Differential scanning calorimetry data thus demonstrates the dependence of crystallization temperature, subsequent 2nd heat melting temperature, and percent crystallinity on the rate of cooling during crystallization. Exemplary embodiments of a strip of insulative cellular polypropylene-based material may have a melting temperature between about 160°C (320°F) and about 172°C (341.6°F), a crystallization temperature between about 108°C (226.4°F) and about 135°C (275°F), and a percent crystallinity between about 42% and about 62%.

[00100] In an illustrative embodiment, a method of producing a wrinkle-resistant polymeric container includes cutting a shape in a cross-web direction (CD) from the extruded tube, wherein an outside-of-extruded-tube (OET) surface or layer faces the inside of the container. In an embodiment, a method of producing a wrinkle-resistant polymeric container includes providing an extruded tube of a resin mixture comprising a primary polypropylene resin and cutting a shape in a cross-web direction (CD) from the extruded tube, wherein an outside-of-extruded-tube (OET) surface or layer faces the inside of the container. In an embodiment, a crystal domain size of alpha-phase polypropylene as determined by wide angle X-Ray

diffraction is below 100 Å. In an embodiment, a crystal domain size of beta-phase polypropylene as determined by wide angle X-Ray diffraction is above 190 Å.

[00101] In exemplary embodiments, an extruded sheet of insulative cellular polypropylene-based material had a melting temperature of about 162°C (323.6°F), a crystallization temperature of about 131°C (267.8°F) and a crystallinity degree of about 46% as determined by differential scanning calorimetry at 10°C per minute heating and cooling rate.

[00102] Differential scanning calorimetry (DSC) also unexpectedly revealed that, for all exemplary cup formulations described herein (Cups 1-6), beta-crystallinity is absent from the DSC 2nd heat curve (Fig. 22), but could be identified via wide angle X-ray diffraction (Figs. 23-25). For conventional polypropylene-based foams known to those skilled in the art, beta-crystallinity identified by X-ray wide angle diffraction would lead to an expectation of beta-crystallinity also being identified by differential scanning calorimetry. Thus, a feature of an insulative cellular polypropylene-based material in accordance with the present disclosure is beta-crystallinity that is identifiable by wide angle X-ray diffraction, but **not** by differential scanning calorimetry.

[00103] Furthermore, conventional polypropylene-based foam might be expected to contain alpha- and beta-crystalline phases detectable by wide angle X-ray diffraction. However, the extra peak present at 16.1° in the wide angle X-ray diffraction patterns for all exemplary insulative cellular polypropylene materials described herein (*see*, Figs. 23-25), which peak may be attributed to the presence of the beta-crystalline phase of polypropylene, *i.e.*, the beta-polymorph, or more specifically, to the diffraction of crystal reflections from the $\beta(300)$ plane, is noticeably absent in the wide angle X-ray diffraction pattern of a sample of conventional polypropylene-based foam (Sample B in Fig. 25). Thus, whereas conventional polypropylene-based foam appears to include pure alpha-crystalline phase, the insulative cellular polypropylene-based material of the present disclosure includes a **mixture** of alpha- and beta-crystalline phases.

[00104] It was found unexpectedly that the OET surface works favorably in a compression mode without causing appreciable creasing, and therefore that an insulative cup (or other structure) may be made with the OET surface facing inside of the insulative cup. In an exemplary embodiment, a crease of about 200 microns deep was seen as a fold where the cell wall collapsed under the compression forces when the InET surface faces inside of the insulative cup (*see* Fig. 20 and Fig. 21). The difference in the resistance of the InET layer and the OET

layer to compression force may be due to difference in the morphology of the layers because they were crystallized at different cooling rates. Interestingly, however, microscopy revealed that cell size appearance in layers close to the surface appears to be the same for InET and OET, nor is there any difference detected between InET and OET by differential scanning calorimetry.

[00105] In exemplary embodiments of formation of an extruded sheet of insulative cellular polypropylene-based material, the InET surface may be cooled by a combination of water cooling and compressed air. The OET surface may be cooled by compressed air by using a torpedo with circulating water and air outlet. Faster cooling may result in the formation of smaller size crystals. Typically, the higher the cooling rate, the greater the relative amount of smaller crystals that are formed. X-Ray diffraction analysis of an exemplary extruded sheet of insulative cellular polypropylene-based material was conducted on Panalytical X'pert MPD Pro diffractometer using Cu radiation at 45KV/40mA. It was confirmed that, while the degree of crystallinity is the same for InET and OET, the OET surface had smallest alpha-domain size of about 99 Å, highest beta-domain size (231 Å) and K-value of 28, while the InET surface compared to OET surface had a larger alpha-domain size of about 121 Å, smaller beta-domain size of 183 Å and higher content of beta-domain as seen from the K-value of 37. (see, Table 7 from Cups 1-5). Without wishing to be bound by theory, it is believed that a higher cooling rate for the OET surface influenced a crystal domain size therein, which, as a result enables the OET surface due to its unique morphology to better withstand a compression force without irreversible deformation.

[00106] The most direct evidence of partially crystalline structure of polymers is provided by X-ray diffraction studies. There is a close relation between regularity of molecular structure and ability of polymer to crystallize. The term lamellae refers to a structure described as single polymer crystal. Lamellae of different polymers have the same general appearance, being composed of thin, flat platelets about 100 Å thick and often many microns in lateral dimensions. The thickness of the lamellae depends on crystallization temperature and any subsequent annealing treatment. Since the molecules comprising the polymers are at least 1000 Å long and the lamellae are only about 100 Å thick, the only plausible explanation is that the polymer chains are folded. Fringed micelle models or fringe crystalline models of the structures of polymer crystals formed from melts states that polymer chains are precisely aligned over distances corresponding to dimensions of the crystallites, but indicate more disordered segments of amorphous regions around them.

[00107] The defect structure of highly crystalline polymers is another theory used to describe X-ray diffraction patterns from polymer crystals. Defect-crystal concept accounts for X-ray diffraction pattern broadening due to (1) point defects, such as vacant sites and polymer chain ends, (2) dislocations of polymer edges, (3) two-dimensional imperfections in fold surfaces, (4) chain-disorder defects, and (5) amorphous defects. While all listed factors contribute in part to X-ray line broadening, it is not known exactly how large such an impact is for every specific polymer. For all practical purposes of comparing and ranking one polymer structure versus another in terms of larger or smaller crystal domain size, wide-angle X-ray diffraction is commonly used. In wide-angle X-Ray diffraction, the final crystal domain size is obtained in units of Angstrom ($\text{\AA}$).

[00108] For all practical purposes of ranking, measuring, and describing aspects of the present disclosure in terms of crystal domain size, wide angle X-ray scattering was used as the test method. In the present disclosure, the term crystal domain size means lamellae thickness, and the term X-Ray refers to wide-angle X-Ray diffraction.

[00109] In exemplary embodiments, an extruded strip of insulative cellular polypropylene-based material may have an alpha-domain size below about 200 $\text{\AA}$, beta-domain size above 200 $\text{\AA}$ and K-value of 18 to 30. In exemplary embodiments, an extruded strip of insulative cellular polypropylene-based material may have an alpha-domain size preferably below about 115 $\text{\AA}$, beta-domain size above 220 and K-values 25 to 28. In exemplary embodiments, an extruded strip of insulative cellular polypropylene-based material may have a K-value of less than 30.

[00110] The present disclosure provides material characterized by the crystalline structure of the polypropylene foam to control morphology and the crease-resistant properties.

[00111] An insulative cellular polypropylene-based material of the present disclosure satisfies a need for a material that can be formed into an article, such as an insulative cup, that includes the features of wrinkle-resistance and crease-resistance as described herein, as well as many, if not all, of the features of insulative performance, recyclability, puncture resistance, frangibility resistance, and microwaveability, which features are described in U.S. Patent Application Nos. 13/491,007 and 13/491,327 both of which are incorporated herein by reference in their entirety. Such polymeric material has an alpha phase and beta phase detectable by X-ray analysis, but with only alpha-phase identifiable by DSC.

[00112] In exemplary embodiments, a formulation includes at least two polymeric materials. In one exemplary embodiment, a primary or base polymer comprises a high melt

strength polypropylene that has long chain branching. In one exemplary embodiment, the polymeric material also has non-uniform dispersity. Long chain branching occurs by the replacement of a substituent, *e.g.*, a hydrogen atom, on a monomer subunit, by another covalently bonded chain of that polymer, or, in the case of a graft copolymer, by a chain of another type. For example, chain transfer reactions during polymerization could cause branching of the polymer. Long chain branching is branching with side polymer chain lengths longer than the average critical entanglement distance of a linear polymer chain. Long chain branching is generally understood to include polymer chains with at least 20 carbon atoms depending on specific monomer structure used for polymerization. Another example of branching is by crosslinking of the polymer after polymerization is complete. Some long chain branch polymers are formed without crosslinking. Polymer chain branching can have a significant impact on material properties.

[00113] In illustrative embodiments, a polymeric material includes a primary base resin. In illustrative embodiments, a base resin may polypropylene. In illustrative embodiments, an insulative cellular non-aromatic polymeric material comprises a polypropylene base resin having a high melt strength, a polypropylene copolymer or homopolymer (or both). In an embodiment, a formulation of the polymeric material comprises about 50 to about 100 wt% of the primary base resin. Suitably, a formulation comprises about 70 to about 100 wt% of a primary base resin. Suitably, a formulation comprises about 50 to about 99 wt% of a primary base resin. Suitably, a formulation comprises about 50 to about 95 wt% of a primary base resin. Suitably, a formulation comprises about 50 to about 85 wt% of a primary base resin. Suitably, a formulation comprises about 55 to about 85 wt% of the primary base resin. As defined hereinbefore, any suitable primary base resin may be used. One illustrative example of a suitable polypropylene base resin is DAPLOY™ WB140 homopolymer (available from Borealis A/S), a high melt strength structural isomeric modified polypropylene homopolymer (melt strength = 36, as tested per ISO 16790 which is incorporated by reference herein, melting temperature = 325.4°F (163°C) using ISO 11357

[00114] In illustrative embodiments, a polymeric material includes a polypropylene copolymer or homopolymer (or both). In another embodiment, a polymeric material comprises about 0 to about 50 wt% of a secondary resin. In an embodiment, a polymeric material comprises about 0 to about 50 wt% of a secondary resin. In an embodiment, a polymeric material comprises about 0 to about 50 wt% of a secondary resin. In an embodiment, a polymeric material does not have a secondary resin. In a particular embodiment, a secondary

resin can be a high crystalline polypropylene homopolymer, such as F020HC (available from Braskem), and PP 527K (available from Sabic).

[00115] In exemplary embodiments, a secondary resin may be or may include polyethylene. In exemplary embodiments, a secondary resin may include low density polyethylene, linear low density polyethylene, high density polyethylene, ethylene-vinyl acetate copolymers, ethylene-ethylacrylate copolymers, ethylene-acrylic acid copolymers, polymethylmethacrylate mixtures of at least two of the foregoing and the like.

[00116] The polymer resins may be blended with any additional desired components and melted to form a resin formulation.

[00117] In one aspect of the present disclosure, at least one slip agent may be incorporated into a formulation of the polymeric material to aid in increasing production rates. A slip agent (also known as a process aid) is a term used to describe a general class of materials which are added to a resin mixture and provide surface lubrication to the polymer during and after conversion. Slip agents may also reduce or eliminate die drool. Representative examples of slip agent materials include amides of fats or fatty acids, such as, but not limited to, erucamide and oleamide. In one exemplary aspect, amides from oleyl (single unsaturated C₁₈) through erucyl (C₂₂ single unsaturated) may be used. Other representative examples of slip agent materials include low molecular weight amides and fluoroelastomers. Combinations of two or more slip agents can be used. Slip agents may be provided in a master batch pellet form and blended with the resin formulation.

[00118] In another embodiment, a formulation comprises about 0 to about 10 wt% of a slip agent. In an embodiment, a formulation comprises about 0 to about 5 wt% of a slip agent. In a further embodiment, a formulation comprises about 0 to about 3 wt% of a slip agent. Any suitable slip agent may be used. In a particular embodiment, a slip agent is the linear low-density polyethylene, AmpacetTM 102823.

[00119] In another embodiment, a formulation comprises about 0 to about 10 wt% of a colorant. In an embodiment, a formulation comprises about 0 to about 5 wt% of a colorant. In a further embodiment, a formulation comprises about 0 to about 3 wt% of a colorant. In another embodiment, a formulation comprises about 0.5 to about 1.5 wt% of a colorant. Any suitable colorant may be used. In a particular embodiment, a colorant is TiO₂.

[00120] One or more nucleating agents are used to provide and control nucleation sites to promote formation of cells, bubbles, or voids in the molten resin during the extrusion process.

A nucleating agent refers to a chemical or physical material that provides sites for cells to form in a molten resin mixture. Nucleating agents may be physical agents or chemical agents. Suitable physical nucleating agents have desirable particle size, aspect ratio, and top-cut properties, shape, and surface compatibility. Examples include, but are not limited to, talc, CaCO_3 , mica, kaolin clay, chitin, aluminosilicates, graphite, cellulose, and mixtures of at least two of the foregoing. A nucleating agent may be blended with the polymer resin formulation that is introduced into the hopper. Alternatively, a nucleating agent may be added to a molten resin mixture in an extruder. When the chemical reaction temperature is reached the nucleating agent acts to enable formation of bubbles that create cells in the molten resin. An illustrative example of a chemical blowing agent is citric acid or a citric acid-based material. After decomposition, a chemical blowing agent forms small gas cells which further serve as nucleation sites for larger cell growth from physical blowing agents or other types thereof. One representative example is Hydrocerol™ CF-40E™ (available from Clariant Corporation), which contains citric acid and a crystal nucleating agent. Another representative example is Hydrocerol™ CF-05E™ (available from Clariant Corporation), which contains citric acid and a crystal nucleating agent. In illustrative embodiments one or more catalysts or other reactants may be added to accelerate or facilitate the formation of cells.

[00121] In certain exemplary embodiments, one or more blowing agents may be incorporated. Blowing agent means a physical or a chemical material (or combination of materials) that acts to expand nucleation sites. Nucleating agents and blowing agents may work together. A blowing agent acts to reduce density by forming cells in the molten resin. A blowing agent may be added to the molten resin mixture in the extruder. Representative examples of physical blowing agents include, but are not limited to, carbon dioxide, nitrogen, helium, argon, air, water vapor, pentane, butane, or other alkane mixtures of the foregoing and the like. In certain exemplary embodiments, a processing aid may be employed that enhances the solubility of the physical blowing agent. Alternatively, a physical blowing agent may be a hydrofluorocarbon, such as 1,1,1,2-tetrafluoroethane, also known as R134a, a hydrofluoroolefin, such as, but not limited to, 1,3,3,3-tetrafluoropropene, also known as HFO-1234ze, or other haloalkane or haloalkane refrigerant. Selection of a blowing agent may be made to take environmental impact into consideration.

[00122] In exemplary embodiments, physical blowing agents are typically gases that are introduced as liquids under pressure into a molten resin via a port in an extruder. As the molten resin passes through the extruder and the die head, the pressure drops causing the physical

blowing agent to change phase from a liquid to a gas, thereby creating cells in the extruded resin. Excess gas blows off after extrusion with the remaining gas being trapped in the cells in the extrudate.

[00123] Chemical blowing agents are materials that degrade or react to produce a gas. Chemical blowing agents may be endothermic or exothermic. Chemical blowing agents typically degrade at a certain temperature to decompose and release gas. In one aspect a chemical blowing agent may be one or more materials selected from the group consisting of azodicarbonamide; azodiisobutyro-nitrile; benzenesulfonhydrazide; 4,4-oxybenzene sulfonylsemicarbazide; *p*-toluene sulfonyl semi-carbazide; barium azodicarboxylate; *N,N'*-dimethyl-*N,N'*-dinitrosoterephthalamide; trihydrazino triazine; methane; ethane; propane; *n*-butane; isobutane; *n*-pentane; isopentane; neopentane; methyl fluoride; perfluoromethane; ethyl fluoride; 1,1-difluoroethane; 1,1,1-trifluoroethane; 1,1,1,2-tetrafluoro-ethane; pentafluoroethane; perfluoroethane; 2,2-difluoropropane; 1,1,1-trifluoropropane; perfluoropropane; perfluorobutane; perfluorocyclobutane; methyl chloride; methylene chloride; ethyl chloride; 1,1,1-trichloroethane; 1,1-dichloro-1-fluoroethane; 1-chloro-1,1-difluoroethane; 1,1-dichloro-2,2,2-trifluoroethane; 1-chloro-1,2,2,2-tetrafluoroethane; trichloromonofluoromethane; dichlorodifluoromethane; trichlorotrifluoroethane; dichlorotetrafluoroethane; chloroheptafluoropropane; dichlorohexafluoropropane; methanol; ethanol; *n*-propanol; isopropanol; sodium bicarbonate; sodium carbonate; ammonium bicarbonate; ammonium carbonate; ammonium nitrite; *N,N'*-dimethyl-*N,N'*-dinitrosoterephthalamide; *N,N'*-dinitrosopentamethylene tetramine; azodicarbonamide; azobisisobutyronitrile; azocyclohexylnitrile; azodiaminobenzene; bariumazodicarboxylate; benzene sulfonyl hydrazide; toluene sulfonyl hydrazide; *p,p'*-oxybis(benzene sulfonyl hydrazide); diphenyl sulfone-3,3'-disulfonyl hydrazide; calcium azide; 4,4'-diphenyl disulfonyl azide; and *p*-toluene sulfonyl azide.

[00124] In one aspect of the present disclosure, where a chemical blowing agent is used, a chemical blowing agent may be introduced into a resin formulation that is added to a hopper.

[00125] In one aspect of the present disclosure, a blowing agent may be a decomposable material that forms a gas upon decomposition. A representative example of such a material is citric acid or a citric-acid based material. In one exemplary aspect of the present disclosure it may be possible to use a mixture of physical and chemical blowing agents.

[00126] In another embodiment, a formulation comprises about 0 to about 20 wt% of a nucleating agent. In an embodiment, a formulation comprises about 0 to about 10 wt% of a

nucleating agent. In another embodiment, a formulation comprises about 0 to about 5 wt% of a nucleating agent. In another embodiment, a formulation comprises about 0.1 to about 2.5 wt% of a nucleating agent. In an embodiment, a formulation comprises about 0.35 to about 1.5 wt% of a nucleating agent. Any suitable nucleating agent or nucleating agents may be used. In a particular embodiment, the nucleating agent is selected from the group consisting of HydrocerolTM CF-40ETM (available from Clariant Corporation), HPR-803i fibers (available from Milliken), talc, and mixtures thereof.

[00127] In another embodiment, a nucleating agent comprises a primary nucleating agent and a secondary nucleating agent. In an embodiment, a formulation comprises about 0.01 to about 10 wt% of a primary nucleating agent. In an embodiment, a formulation comprises about 0.01 to about 5 wt% of a primary nucleating agent. In an embodiment, a formulation comprises about 0.01 to about 0.15 wt% of a primary nucleating agent. In an embodiment, a formulation comprises about 0.02 to about 0.1 wt% of a primary nucleating agent. In an embodiment, a formulation comprises about 0.03 to about 0.7 wt% of a primary nucleating agent. Any suitable primary nucleating agent may be used. A primary nucleating agent may be defined as a chemical blowing agent or chemical foaming agent, itself comprising a nucleating agent. In a particular embodiment, a primary nucleating agent is HydrocerolTM CF-40ETM (available from Clariant Corporation).

[00128] In an embodiment, a formulation comprises about 0.01 to about 10 wt% of a secondary nucleating agent. In an embodiment, a formulation comprises about 0.01 to about 5 wt% of the secondary nucleating agent. In an embodiment, a formulation comprises about 0.1 to about 2.2 wt% of a secondary nucleating agent. In an embodiment, a formulation comprises about 0.3 to about 1.7 wt% of a secondary nucleating agent. In an embodiment, a formulation comprises about 0.4 to about 1.5 wt% of a secondary nucleating agent. In an embodiment, a formulation comprises about 0.45 to about 1.25 wt% of a secondary nucleating agent. Any suitable secondary nucleating agent may be used. In a particular embodiment, a secondary nucleating agent is from HPR-803i fibers (available from Milliken) or talc.

[00129] Formulations described herein can be used to form insulative, polymeric containers. In an embodiment, a container can be a cup. In an embodiment, a container can be a microwaveable tray.

EXAMPLES

[00130] The following examples are set forth for purposes of illustration only. Parts and percentages appearing in such examples are by weight unless otherwise stipulated.

First aspect of the disclosure

[00131] Example 1: Formulation, Extrusion, and Sheet Formation

[00132] An exemplary formulation used to illustrate the present disclosure is presented below and is described in U.S. Provisional Application Serial No. 61/719,096, the disclosure of which is hereby incorporated herein by reference in its entirety:

[00133] DAPLOY™ WB140 polypropylene homopolymer (available from Borealis A/S) was used as the polypropylene base resin. F020HC, available from Braskem, a polypropylene homopolymer resin, was used as the secondary resin. The two resins were blended with: Hydrocerol™ CF-40E™ as a chemical blowing agent, talc as a nucleation agent, CO₂ as a blowing agent, a slip agent, and titanium dioxide as a colorant. Percentages were:

81.45% Primary resin: high melt strength polypropylene Borealis WB140 HMS

15% Secondary resin: F020HC (Braskem) homopolymer polypropylene

0.05% Chemical blowing agent: Clariant Hydrocerol CF-40E™

0.5% Nucleation agent: Heritage Plastics HT4HP Talc

1% Colorant: Colortech 11933-19 TiO₂ PP

2% Slip agent: Ampacet™ 102823 Process Aid LLDPE (linear low-density polyethylene), available from Ampacet Corporation

[00134] The formulation described above was added to an extruder hopper. The extruder heated the formulation to form a molten resin mixture. To this mixture was added 2.2 lbs/hr CO₂, which was injected into the resin blend to expand the resin and reduce density. The mixture thus formed was extruded through a die head into a sheet as described in U.S. Application Serial No. 13/491,007, the disclosure of which is hereby incorporated herein by reference in its entirety.

[00135] High resolution microscopy may be used to determine the dimensional properties of microcellular polymeric material. The Keyence VHX-1000 Digital Microscope was used to determine the dimensional properties of insulative cellular polypropylene-based material cells of the present disclosure. In one exemplary embodiment, cell length may be the dimensional property denoting maximum distance from top to bottom of cells running parallel to the machine direction. In another exemplary embodiment, cell length may also be the dimensional property denoting maximum distance from top to bottom of cells running parallel to the cross direction. In yet another exemplary embodiment, cell width may be the dimensional property denoting maximum distance from top to bottom of cells running perpendicular to the machine and cross direction. In still another exemplary embodiment, cell wall thickness may be the dimensional property denoting maximum distance between separated cell voids across a line running perpendicular to the machine and cross direction.

[00136] In order to assess the effect of cell morphology of an extruded sheet of insulative cellular polypropylene-based material on the quality of an article formed therewith, such as a cup, a minimum of 700 measurement points were chosen for each of the length and width dimensional properties in order to verify consistency throughout a strip of the material. A minimum of 200 measurement points were chosen for cell wall thickness as a dimensional property in order to verify consistency throughout the strip of insulative cellular polypropylene-based material. In one exemplary embodiment, a sheet of insulative cellular polypropylene-based material may be extruded from an enclosed die volume at an angle of 44°. In another exemplary embodiment, a sheet of insulative cellular polypropylene-based material may be extruded from an enclosed die volume at an angle of 90°. A sheet of insulative cellular polypropylene-based material extruded at an angle of 44° is referred to herein as Material C. A sheet of insulative cellular polypropylene-based material extruded at an angle of 90° is referred to herein as Material D. Strips of insulative cellular polypropylene-based material from 44° and 90° exit angles were quantitatively compared as shown in Figs. 1-3.

[00137] Example 1: Test method

[00138] The typical testing method used for cell morphology measurement was as follows:

1. Cut a strip of insulative cellular polypropylene-based material along the cross direction (CD) and machine direction (MD).
2. Hold the material with a flat clamp and use a razor blade to perform a fine shave.
3. Focus the microscope at 100x and adjust lighting onto the material.

4. Perform length and width measurements of each unique cell in the CD and MD orientation and record values (*see*, Fig. 1).
5. Perform cell wall thickness measurements across 3-4 tangent lines to overall length of each unique cell in the CD and MD orientation and record the values (*see*, Fig. 2).
6. Move microscope visual field so the bottom of the most upper incomplete cell is touching the bottom of the screen.
7. Repeat steps 4-5 on each new unique cell until at least 0.500" of the strip is measured.

[00139] A sheet of insulative cellular polypropylene-based material produced as described herein typically possessed a density of about 0.1615 g/cm³ and material thickness of about 0.066 inches (1.6764 mm).

[00140] Example 1: Test Results

[00141] The cell morphology of an extruded sheet of insulative cellular polypropylene-based material exiting the enclosed die volume at angles of 44° and 90° differed greatly in terms of cell height, cell width, cell aspect ratio, and cell wall thickness (*see*, Table 1). In the machine direction or MD, Material C had an average length of 19.54 mils (49.63 mm), an average width of 8.53 mils (21.67 mm), an average cell wall thickness of 1.02 mils (2.59 mm), and average aspect ratio of 2.29. In the machine direction or MD, Material D had an average length of 17.01 mils (43.21 mm), an average width of 5.22 mils (13.26 mm), an average cell wall thickness of 0.77 mils (1.96 mm), and average aspect ratio of 3.26.

[00142] In the cross-web direction or CD, Material C had an average length of 18.45 mils (46.86 mm), an average width of 8.28 mils (21.03 mm), an average cell wall thickness of 0.96 mils (2.44 mm), and average aspect ratio of 2.23. In the cross-web direction or CD, Material D has an average length of 16.43 mils (41.73 mm), an average width of 5.30 mils (13.46 mm), an average cell wall thickness of 0.84 mils (2.13 mm), and average aspect ratio of 3.10.

[00143] Moreover, formation of wrinkled insulative cellular polypropylene-based material was found to occur when the exit angle of curvature increased from 44° to 90° (*see*, Example 1, Figs. 1-3). Based on these results, it can be concluded that die exit angles from enclosed die volumes create different material morphology, with differing resistance to wrinkling and/or creasing, when recipe and process conditions are held constant. In one exemplary embodiment, wrinkle-resistant insulative cellular polypropylene-based material may be created concomitantly with a decrease in die exit angle. The lower the angle of die exit, the

easier it is to control and orient the cell aspect ratio, thus enabling preparation of a sheet of insulative cellular polypropylene-based material that possesses cell aspect ratios close to 1. In exemplary embodiments, die exit angles within an inclusive range of 50° – 60° may produce wrinkle-resistant insulative cellular polypropylene-based material. In other exemplary embodiments, die exit angles within an inclusive range of 40° – 50° may produce wrinkle-resistant insulative cellular polypropylene-based material. In other exemplary embodiments, die exit angles within an inclusive range of 30° – 40° may produce wrinkle-resistant insulative cellular polypropylene-based material. In other exemplary embodiments, die exit angles within an inclusive range of 20° – 30° may produce wrinkle-resistant insulative cellular polypropylene-based material. In other exemplary embodiments, die exit angles within an inclusive range of 10° – 20° may produce wrinkle-resistant insulative cellular polypropylene-based material. In other exemplary embodiments, die exit angles within an inclusive range of 0° – 10° may produce wrinkle-resistant insulative cellular polypropylene-based material. The higher the angle of die exit, the more oriented the cell aspect ratio becomes, especially in the MD direction, *i.e.*, the direction parallel to flow of insulative cellular polypropylene-based material. Without wishing to be bound by theory, lower cell aspect ratios may reduce local stress concentrations that are experienced during convolution of insulative cellular polypropylene-based material, thus leading to wrinkle-resistant and/or crease-resistant material.

Table 1: MD and CD Dimensional Attributes of Material C and Material D

	Cells dimensions [milli inches]	44° Material C	90° Material D
MD	Cell length	19.54	17.01
	Cell width	8.53	5.22
	MD Cell Aspect Ratio	2.29	3.26
	Cell Wall Thickness	1.02	0.77
CD	Cell length	18.45	16.43
	Cell width	8.28	5.30
	CD Cell Aspect Ratio	2.23	3.10
	Cell Wall Thickness	0.96	0.84

[00144] Example 2: Formulation, Extrusion, and Sheet Formation

[00145] High resolution microscopy may be used to determine the dimensional properties of microcellular polymeric materials. The Keyence VHX-1000 Digital Microscope and Keyence VHX-2000 Digital Microscope were used to determine the dimensional properties of insulative cellular polypropylene-based material cells from the present disclosure.

[00146] Nine specified formulations with dissimilar processing conditions (*see*, Table 2) produced cell dimensional properties that were found to follow a power law model with high accuracy and produce material that may possess wrinkle resistance. The following variables were held constant throughout iterations 1-18: 1° extruder temperature, 2° temperature, extruder speed, sheet pull rate, cooling mandrel diameter, cooling mandrel temperature, and overall die temperature (*see*, Table 3A). The following variables were altered throughout the aforementioned trial iterations: formula, exit die pressure, die lip angle, die air ring cooling [l/min], and orientation (*see*, Table 3A). The following variables were held constant throughout iterations 19-45: 1° extruder temperature, extruder speed, sheet pull rate, cooling mandrel diameter, cooling mandrel temperature, and overall die temperature (*see*, Table 3B). The

following variables were altered throughout the aforementioned trial iterations: 2° temperature, exit die pressure, die air ring cooling [l/min], CO₂ %, and orientation (*see*, Table 3B). Iterations 46-50 were conducted in a manner similar to iterations 1-45 in order to investigate the occurrence of creasing during convolution of insulative cellular polypropylene-based material into a circular article (*see*, Table 3C).

[00147] Cross-web direction and machine direction dimensional attributes of 50 different iterations with nine specified formulations were incorporated in the analysis in order to produce data sufficient for high accuracy and precision, as shown in Figs. 1-3. The specific formulation described above for Example 1 as well as eight other formulations were used to illustrate this aspect of present disclosure (*see*, Table 2).

Table 2: Formulations and Processing Conditions

Formula #	1° Resin	2° Resin	Chemical Blowing Agent	Additive #1	Additive #2	Additive #3	Additive #4	CO ₂ (Lbs/Hr) [Table 3B]
1	81.5% Borealis WB140 HMS	15% Braskem F020HC	None	0.5% Heritage Plastics HT4HP Talc	1% Colortech 11933-19 TiO ₂ -PP	2% Ampacet™ 102823 Process Aid	None	2.2-2.3
2	82.5% Borealis WB140 HMS	15% Braskem F020HC	None	0.5% Techmer PM PPM16466 Silica	None	2% Ampacet™ 102823 Process Aid	None	2.2-2.3
3	82.5% Borealis WB140 HMS	15% Braskem F020HC	None	0.5% Techmer PM PPM16464 Silica	None	2% Ampacet™ 102823 Process Aid	None	2.2-2.3
4	82.5% Borealis WB140 HMS	15% Braskem F020HC	None	0.5% Heritage Plastics HT4HP Talc	None	2% Ampacet™ 102823 Process Aid	None	2.2-2.3
5	81.5% Borealis WB140 HMS	15% Braskem F020HC	None	0.5% Heritage Plastics HT4HP Talc	1% Cell Stabilizer	2% Ampacet™ 102823 Process Aid	None	2.2-2.3
6	81.45% Borealis WB140 HMS	15% Braskem F020HC	0.05% Clariant Hydroce rol CF-40E™	0.5% Heritage Plastics HT4HP Talc	1% Colortech 11933-19 TiO ₂ -PP	2% Ampacet™ 102823 Process Aid	None	2.2-2.4
7	81.45% Borealis WB140 HMS	15% Braskem F020HC	0.05% Clariant Hydroce rol CF-40E™	0.5% Techmer PM PPM16466 Silica	1% Colortech 11933-19 TiO ₂ -PP	2% Ampacet™ 102823 Process Aid	None	2.2-2.4
8	79.95% Borealis WB140 HMS	15% Braskem F020HC	0.05% Clariant Hydroce rol CF-40E™	2% Heritage Plastics HT4HP Talc	1% Colortech 11933-19 TiO ₂ -PP	2% Ampacet™ 102823 Process Aid	None	2.8
9	77.95% Borealis WB140 HMS	15% Braskem F020HC	0.05% Clariant Hydroce rol CF-40E™	2% Heritage Plastics HT4HP Talc	1% Colortech 11933-19 TiO ₂ -PP	2% Ampacet™ 102823 Process Aid	2% Techmer PM PPM16466 Silica	2.8

Table 3A: Trial Iterations

Iteration #	Formula #	Die Pressure [bar]	Cooling L/min	Orientation	Wrinkle
1	8	85	1500	CD	No
2	1	75	0	MD	Yes
3	9	85	1500	CD	No
4	9	85	1500	MD	No
5	6	86	1950	CD	Yes
6	6	86	1950	MD	Yes
7	6	83	1440	CD	No
8	6	83	1440	MD	No
9	7	81	2000	CD	No
10	7	81	2000	MD	No
11	3	75	0	MD	Yes
12	3	75	850	MD	Yes
13	2	75	850	MD	Yes
14	2	75	0	MD	Yes
15	4	75	0	MD	Yes
16	4	75	850	MD	Yes
17	5	75	850	MD	Yes
18	5	75	0	MD	Yes

Table 3B: Trial Iterations (continued)

Iteration #	Formula #	Die Pressure [psi]	Cooling L/min	Secondary Extruder Temp	CO2 %	Orientation	Wrinkle
19	1	1080-1160	1900	335	2.2	CD	No
20	1	1080-1160	1900	335	2.2	CD	No
21	1	1080-1160	1900	335	2.2	CD	No
22	1	1080-1160	1900	335	2.2	CD	No
23	1	1080-1160	1900	335	2.2	CD	No
24	1	1050	1400	330	2.2	CD	Yes
25	1	1050	1400	330	2.2	MD	Yes
26	1	1380	2000	330	2.2	MD	No
27	1	1380	2000	330	2.2	CD	No
28	1	1380	2000	330	2.2	MD	No
29	1	1050	2000	330	2.6	CD	Yes
30	1	1050	2000	330	2.6	MD	Yes
31	1	1380	1400	330	2.6	CD	No
32	1	1380	1400	330	2.6	MD	No
33	1	1050	2000	350	2.2	CD	Yes
34	1	1050	2000	350	2.2	MD	Yes
35	1	1380	1400	350	2.2	CD	No
36	1	1380	1400	350	2.2	MD	No
37	1	1380	1400	350	2.2	MD	No
38	1	1380	1400	350	2.2	MD	No
39	1	1380	1400	350	2.2	MD	No
40	1	1050	1400	350	2.2	CD	Yes
41	1	1050	1400	350	2.2	CD	Yes
42	1	1050	1400	350	2.6	CD	Yes
43	1	1050	1400	350	2.6	MD	Yes
44	1	1380	2000	350	2.2	CD	No
45	1	1380	2000	350	2.2	MD	No

Table 3C: Trial Iterations (continued)

Iteration	Formula	Orientation	Wrinkle
46	1	MD	No
47	1	MD	No
48	1	MD	Yes
49	1	CD	Yes
50	1	MD	No

[00148] Example 2: Test method

[00149] The typical testing method used for cell morphology measurement was as follows:

1. Cut a strip of insulative cellular polypropylene-based material along the cross direction (CD) and machine direction (MD).
2. Hold the material with a flat clamp and use a razor blade to perform a fine shave.
3. Focus the microscope at 100x and adjust lighting onto the material.
4. Perform length and width measurements of each unique cell in the CD and MD orientation and record values (*see*, Fig. 1).
5. Count the number of measured unique cells and record the values (*see*, Fig. 1).
6. Perform cell wall thickness measurements across 3-4 tangent lines to overall length of each unique cell in the CD and MD orientation and record the values (*see*, Fig. 2).
7. Perform three overall strip thickness measurements starting from the bottom of the first measured cell group, to the middle of the cell group, to the top of the cell group (*see*, Fig. 3).
8. Perform an overall length measurement starting from the lowest complete cell to the highest complete cell (*see*, Fig. 3).
9. Move microscope visual field so the bottom of the most upper incomplete cell is touching the bottom of the screen.
10. Repeat steps 4-9 on each new unique cell until about 0.200" to 0.800" of the strip is measured. Ensure that the overall length and cell composition does not overlap. Each overall length measurement after the first measurement is taken from the top of the previous highest complete cell to the top of the current highest complete cell.

[00150] A sheet of insulative cellular polypropylene-based material produced as described herein typically possessed a density of about 0.1615 g/cm^3 and material thickness of about 0.066 inches (1.6764 mm).

[00151] Example 2: Test Analysis

[00152] All cell measurements were performed on over 7500 unique cell units from 50 different samples produced in various ways as described above. Although the maximum window view range of the Keyence digital microscope was 100 mils by 100 mils, careful attention was paid to ensure that each cell was unique and that the overall height and width of the measured strip was an average of values. A total of six (6) different dimensional parameters were measured for iterations 1-18. In one exemplary embodiment, dimensional parameters of overall strip length (L), overall strip thickness (T), and total numbers of cells in the measured strip area (n) may be classified as bulk properties because they describe an overall cell property. In another exemplary embodiment, dimensional parameters of cell length (l), cell width (w), and cell wall thickness (t) may be classified as cell properties because they describe each cell unit. A total of five (5) different dimensional parameters were measured for iterations 19-50. In one exemplary embodiment, dimensional parameters of overall strip length (L), overall strip thickness (T), and total numbers of cells in the measured strip area (n) may be classified as bulk properties because they describe an overall cell property. In another exemplary embodiment, dimensional parameters of cell length (l) and cell width (w) may be classified as cell properties because they describe each cell unit. Each set of dimensional values was separately analyzed to ascertain a correlation between bulk properties and cell properties. Cell density (p) was used to normalize each cell number value because each of the 50 iterations possessed a different number of cells per area (cells/m^2) due to different strip geometries. Cell density is calculated as the total number of cells in a given strip (n) divided by the overall strip length (L) and overall strip thickness (T), raised to the $3/2$ power, as shown in Equation 1. Cell aspect ratio (A) is calculated as the average cell length (l) divided by the average cell width (w) of given iterations, as shown in Equation 2.

Equation 1:

$$p = (n/TL)^{3/2}$$

Equation 2:

$$A = (l/w)$$

[00153] Equation 1 transforms the units from cells per unit area (cells/in²) into cells per unit volume (cells/in³). Through mathematical manipulation of the denominator, the area (m²) is raised to the 3/2 power to transform the dimensional property into volume with correct units (m³). The same correlative effect is applied to the number of cells for consistency. Therefore, cell density is independently measured and calculated from the average bulk properties, as shown in Table 4 and Table 5. Cell properties such as cell length, cell width, and cell wall thickness are also independently measured and the average is calculated, also as shown in Table 4 and Table 5. By comparing independent values, quantitative correlations can be established to predict the occurrence of wrinkle-resistant material based solely on comparison of independent variables.

Table 4: Test Analysis Data From Iterations 1-18

Iteration #	Number of Cells in Strip (cells)	Strip Length (mils)	Strip Thickness (mils)	Cell Density (cells/in ³)	Cell Length (Mils)	Cell Width (Mils)	Cell Wall Thickness (Mils)	Cell Aspect Ratio
1	265	654.48	59.05	5.68 x 10 ⁵	14.22	7.33	0.96	1.94
2	101	521.43	84.41	1.10 x 10 ⁵	34.28	10.87	1.83	3.15
3	398	693.10	60.79	9.18 x 10 ⁵	11.94	6.70	0.78	1.78
4	290	635.96	68.79	5.40 x 10 ⁵	19.78	6.56	0.93	3.02
5	500	759.73	70.83	8.96 x 10 ⁵	16.43	5.30	0.84	3.10
6	457	692.33	69.96	9.16 x 10 ⁵	17.01	5.22	0.77	3.26
7	281	752.03	66.41	4.22 x 10 ⁵	18.45	8.28	0.96	2.23
8	276	754.69	69.28	3.84 x 10 ⁵	19.54	8.53	1.02	2.29
9	402	833.86	62.49	6.78 x 10 ⁵	8.09	5.92	0.88	1.37
10	421	833.37	70.72	6.04 x 10 ⁵	9.99	6.17	0.9	1.62
11	39	828.50	50.75	2.82 x 10 ⁴	60.77	14.81	2.40	4.10
12	53	807.00	55.43	4.08 x 10 ⁴	51.27	12.85	2.75	3.99
13	37	931.48	55.28	2.28 x 10 ⁴	68.52	16.36	2.27	4.19
14	29	802.19	58.33	1.54 x 10 ⁴	70.44	20.80	3.12	3.39
15	21	817.08	64.75	7.91 x 10 ³	86.75	24.36	3.43	3.56
16	36	830.59	77.76	1.32 x 10 ⁴	65.06	19.97	2.63	3.26
17	31	825.61	64.22	1.41 x 10 ⁴	65.00	22.00	2.99	2.95
18	28	832.65	61.00	1.29 x 10 ⁴	63.30	20.71	3.56	3.06

Table 5: Test Analysis Data from Iterations 19-50

Iteration #	Cell Length	Cell Width	Cell Density	Cell Aspect Ratio
19	14.73	5.60	6.007E+05	2.63
20	20.72	7.16	4.407E+05	2.89
21	22.04	5.92	4.791E+05	3.72
22	17.95	5.95	6.545E+05	3.02
23	18.41	6.20	5.602E+05	2.97
24	17.02	5.93	910587	2.87
25	17.48	5.29	971383	3.30
26	13.04	5.92	1230737	2.20
27	13.97	6.34	1260693	2.20
28	13.08	6.6	1420564	1.98
29	18.1	5.45	1099014	3.32
30	20.74	6.53	728556	3.18
31	13.2	6.45	1167341	2.05
32	11.72	5.87	1851158	2.00
33	16.08	5.48	1179837	2.93
34	25.03	6.35	683270	3.94
35	14.02	6.05	1215786	2.32
36	11.54	5.94	1544317	1.94
37	10.59	5.46	1630729	1.94
38	10.71	5.52	1650454	1.94
39	10.78	6.1	1713915	1.77
40	16.14	5.43	1061618	2.97
41	19	5	911612	3.80
42	17.07	5.26	1159422	3.25
43	20.36	5.61	933041	3.63
44	14.81	6.51	1006006	2.27
45	12.57	6.05	1405602	2.08
46	12.99	6.38	1345104	2.04
47	13.5	6.03	1355593	2.24
48	21.82	6.69	751112.4	3.26
49	15.74	5.24	1005240	3.00
50	11.07	5.31	1962021	2.08

[0053] Example 2: Test Results

[00154] By correlating cell density bulk property to cell length, cell width, and cell wall thickness cell properties, a strong correlation was found that may predict dimensional properties with respect to cell density, and subsequently cell area. The coefficient of determination (R^2) values produced by Microsoft Excel 2010 power law regression fit demonstrates a high degree of accuracy with regard to the validity of the fitted power law-based model. The power law has an equation form of two dependent variables, x and y, and two independent variables or constants, A and K, as shown in Equation 3 and Equation 4:

Equation 3:

$$y = Ax^K$$

Equation 4:

$$x = (y/A)^{1/K}$$

[00155] In exemplary embodiments, cell density may predict cell length, cell width, and cell wall thickness with R^2 values of 0.945, 0.939, and 0.973 (*see*, Fig. 14, Fig. 15 and Fig. 12, respectively). The closer the R^2 value is to 1, the more accurate the model fit. It is generally accepted that a regression fit value greater than 0.85 demonstrates a strong quantitative correlation between two independent variables, which, in this case, are represented by bulk properties and cell properties.

[00156] In exemplary embodiments, the equation for predicting cell length with respect to cell density may be $y = 1,243,388,528.483x^{-2.626}$, wherein the power law constants for predicting cell length with respect to cell density are $A = 1,243,388,528.483$ and $K = -2.626$. In other exemplary embodiments, the equation for predicting cell width with respect to cell density may be $y = 426,736,129.761x^{-3.417}$, wherein the power law constants for predicting cell width with respect to cell density are $A = 426,736,129.761$ and $K = -3.417$. In other exemplary embodiments, the equation for predicting cell wall thickness with respect to cell density may be $y = 448,002.648x^{-3.053}$, wherein the power law constants for predicting cell wall thickness with respect to cell density are $A = 448,002.648$ and $K = -3.053$.

[00157] The data also illustrate a satisfactory range where insulative cellular polypropylene-based material possesses wrinkle resistance or lacks wrinkles altogether, as defined by Pass and Fail, where Pass means wrinkles and/or creases are not present and Fails means wrinkles and/or creases are present. As shown in Fig. 16 and Fig. 17, the data can be organized in both the machine direction and cross-web direction. From interpretation of the data in Fig. 16, it can be seen that the aspect ratio of cells that run parallel to the circumference (*i.e.*, in the MD, machine direction) may not only play an important role in determining wrinkle resistance, but a more important role than that of either cell density or the aspect ratio of cells running perpendicular to the circumference (*i.e.*, in the CD, cross direction, as shown in Fig. 17).

[00158] In exemplary embodiments (*see*, Fig. 16), insulative cellular polypropylene-based material that possesses a cell aspect ratio in the MD direction of less than about 2.75 may not

wrinkle when convoluted into an article, such as an insulative cup. Illustratively, insulative cellular polypropylene-based material that possesses a cell aspect ratio in the MD direction of 2.5 or less may not wrinkle when convoluted into an article, such as an insulative cup. In other exemplary embodiments (*see*, Fig. 17), insulative cellular polypropylene-based material that possesses a cell aspect ratio in the CD direction of less than about 2.75 may not wrinkle when convoluted into an article, such as an insulative cup. Illustratively, insulative cellular polypropylene-based material that possesses a cell aspect ratio in the CD direction of 2.5 or less may not wrinkle when convoluted into an article, such as an insulative cup. In other exemplary embodiments (*see*, Fig. 17), insulative cellular polypropylene-based material that possesses a cell aspect ratio in the CD direction of about 2.75 to about 4.00 and a cell density of about 300,000 cells/in³ to about 900,000 cells/in³ may not wrinkle when convoluted into an article, such as an insulative cup. In other exemplary embodiments (*see*, Fig. 16), insulative cellular polypropylene-based material that possesses a cell aspect ratio in the MD direction of about 2.75 to about 3.5 and a cell density of about 300,000 cells/in³ to about 700,000 cells/in³ may not wrinkle when convoluted into an article, such as an insulative cup.

[00159] The cell prediction model accurately describes cell growth in the cell width, cell length, and cell wall thickness category and possesses power law functionality, similarly to that seen in many natural phenomena. By taking on a log-log plot form, the correlation is unexpectedly a straight line that penetrates near or through all data points with accuracy. This development provides further evidence for power law correlation and subsequently the ability to model and predict cell growth, as shown in Figs. 8-13.

[00160] As presaged by the wrinkle-resistant versus micro-creasing/macro-creasing results shown in Fig. 4-7, and as summarily illustrated in Fig. 16 and Fig. 17, the present disclosure permits the identification of a control range with respect to cell aspect ratio and cell density, which range permits the manufacture of insulative cups that do not wrinkle and/or crease. Fig. 16 illustrates cell densities in a (cup) convolution process as a function of cell aspect ratio in the machine direction, whereas Fig. 17 illustrates cell densities in a (cup) convolution process as a function of cell aspect ratio in the cross direction. In Fig. 16 and Fig. 17, cell densities that Pass are tolerated without the onset of wrinkling and/or creasing during cup convolution. Conversely, cell densities in Fig. 16 and Fig. 17 that are associated with wrinkling and/or creasing during cup convolution, *i.e.*, that Fail, result in micro-creasing and/or macro-creasing, where micro-creasing and/or macro-creasing are defined as follows:

Micro-Creasing defines small creases inside the cup found in the middle, top, and especially bottom areas; they are generally 1/4" to 1/2" in length and near invisible to the eye unless you look for them.

Macro-Creasing defines large creases inside the cup that run all the way from the bottom to top or tangent to the cup; they are generally cup-length and very visible to the eye.

Second aspect of the disclosure

[00161] Example 3: Sample Cup Formulation and Extrusion

[00162] An exemplary formulation used to illustrate the present disclosure is presented below and is described in U.S. Patent Application Serial No. 13/491/327, filed June 7, 2012 and entitled POLYMERIC MATERIAL FOR AN INSULATED CONTAINER, the disclosure of which is hereby incorporated herein by reference in its entirety:

[00163] DAPLOY™ WB140 high melt strength polypropylene homopolymer (available from Borealis A/S) was used as the primary base resin. F020HC, available from Braskem, a polypropylene homopolymer resin, was used as the secondary resin. The two resins were blended with: Hydrocerol™ CF-40E™ as a primary nucleation agent, talc as a secondary nucleation agent, CO₂ as a blowing agent, a slip agent, and titanium dioxide as a colorant. Formulation I was the following:

80.7% Primary resin: high melt strength polypropylene Borealis WB140 HMS

15.0% Secondary resin: F020HC (Braskem)

0.05% Chemical blowing agent Clariant Hydrocerol™ CF-40E™

0.25% Nucleating agent: Talc

2.0% Colorant: TiO₂ PE (alternatively, PP can be used)

2.0% Slip agent: Ampacet™ 102823 LLDPE (linear low-density polyethylene), available from Ampacet Corporation

[00164] The formulation described above was added to an extruder hopper. The extruder heated the formulation to form a molten resin mixture. To this mixture was added 3.4 lbs/hr

CO₂, which was injected into the resin blend to expand the resin and reduce density. The mixture thus formed was extruded through a die head into a sheet. The sheet was then die-cut and formed into a cup as described in U.S. Patent Application Serial No. 13/491,007, filed June 7, 2012 and entitled INSULATED CONTAINER, the disclosure of which is hereby incorporated herein by reference in its entirety.

[00165] Example 4: Sample Cup Preparations

Cup 1

Insulative cellular polypropylene-based material was extruded with the formulation described above. Die-cut article shapes were oriented in the MD (machine direction) with the longer side of the article oriented along the web direction. Insulated cups were formed with OET facing outside of the insulated cup resulting in multiple creases and wrinkles, some deeper than 5 mm. Fig. 21 shows a microscopy image of the foam cell wall collapsed forming a crease during article formation. The insulated cups were not usable.

Cup 2

The same insulative cellular polypropylene-based material as in Cup 1 was used to make die cut shapes in MD direction, but articles were formed with OET facing inside the insulative cup. Unexpectedly, the insulative cup surface was free of creases and the insulative cups were acceptable for use.

Cup 3

The same insulative cellular polypropylene-based material as in Cup 1 was used to make die cut shapes in CD (cross-web direction), with the longer side of the article oriented across the web. Insulative cups were formed with OET facing outside of the insulative cup. Appearance further improved compared to Cup 2. The insulative cups were usable.

Cup 4

The same insulative cellular polypropylene-based material as in Cup 1 was used to make die cut shapes in CD, with the longer side of the article oriented across the web. Insulative cups were formed with OET tube facing inside of the insulative cup. Appearance further improved compared to Example 4. The insulative cups were usable and had no creases.

Cup 5

Printed polypropylene (PP) film was laminated to the OET layer of the insulative cellular polypropylene-based material of Example 3, the article shape was die cut in MD, and insulated cups were formed with printed layer facing outside of the insulated cup. Appearance was the worst, with creases exceeding 5 mm depth.

Cup 6

Printed polypropylene (PP) film was laminated to the OET layer of the insulative cellular polypropylene-based material of Example 3, the article shape was die cut in CD, and insulated cups were formed with printed layer facing outside of the insulated cup. Appearance improved compared to Cup 5, but did not compare favorably with Cups 2, 3, and 4.

[00166] Table 6: Test Results for Sample Cups 1-6

Sample ID	Direction the shape was cut	Outside of extruded tube (OET) surface location on the formed cup	Visual appearance	Appearance scale (1 - bad, 5 - excellent)
Cup 1 (insulative cellular polypropylene-based material only)	MD	OET – OUTSIDE the cup	Multiple bad creases	2
Cup 2 (insulative cellular polypropylene-based material only)	MD	OET – INSIDE the cup	No creases	4
Cup 3 (insulative cellular polypropylene-based material only)	CD	OET – OUTSIDE the cup	No creases	4
Cup 4 (insulative cellular polypropylene-based material only)	CD	OET - INSIDE the cup	Smooth inside surface, no creases	5
Cup 5 (with printed PP film on OET side)	MD	Printed PP film on OET – OUTSIDE the cup	Deep creases from top to bottom of the cup	1
Cup 6 (with printed PP film on OET side)	CD	Printed PP film on OET – OUTSIDE the cup	Two creases: one along the seam, another opposite to the seam	3

[00167] The cup-forming process that best minimized wrinkling and/or creasing (Cup 4) included a step of cutting the shape in a cross-web direction (CD) from an extruded tube of insulative cellular polypropylene-based material with the OET surface/layer facing the inside of the cup. When (a) the cup shape was cut out in the CD and (b) the cup was obtained from laminating a printed polypropylene film to OET surface/layer facing the outside of the cup as in Cup 6, there was significant improvement in visual appearance. When (a) the shape was cut in

the CD and (b) the printed polypropylene film was laminated to InET surface/layer, the appearance and rim shape further improved compared to Cup 6.

[00168] As evident from microscopy images (Fig. 20 and Fig. 21), the cup is folded under a compressive force when the InET is the inside of a cup, resulting in wrinkles and creases. Unexpectedly, the OET as the inside of a cup does not fold. The OET can withstand a compressive force, despite the fact that there is no difference detected between InET and OET by differential scanning calorimetry. Further, cell size in layers close to the surface appears to be the same for InET and OET as confirmed by microscopy.

[00169] The difference between InET and OET was investigated by wide angle X-Ray diffraction (WAXD) analysis. WAXD analysis was conducted as follows: A sample section with a size of 1" x 1" fixed in a standard sample holder was placed into a Panalytical X'pert MPD Pro diffractometer using Cu radiation at 45KV/40mA. Scans were run over the range of 5° - 50° with a step size of 0.0157° and a counting time of 50 seconds per step. The diffraction patterns for the InET and OET surfaces of the sample were determined. The WAXD patterns of polypropylene exhibited five major peaks located at 14.2°, 16.1°, 17.1°, and 18.6°, corresponding to the diffraction of crystal reflections from the $\alpha(110)$, $\beta(300)$, $\alpha(040)$, $\alpha(130)$, and $\gamma(117)$ planes, respectively. The $\alpha(110)$ peak was used to calculate the crystal domain size as shown at Fig. 23.

[00170] The K-value was calculated using RIR method (Reference Intensity Ratio) to characterize the relative content of the beta-phase in the material in accordance to the following formula:

$$K \text{ value} = (A_{\beta}/(A_{\alpha} + A_{\beta})) \times 100,$$

where

the K value is the content of beta domain expressed as a percent (%);

A_{α} is total area of the alpha-domain peak on WAXD pattern graph corresponding to the diffraction of crystal reflections from the $\alpha(110)$ plane;

A_{β} is the total area of the beta-domain peak on WAXD pattern graph corresponding to the diffraction of crystal reflections from the $\beta(300)$ plane.

[00171] Although the degree (percent) of crystallinity was the same for InET and OET, the size of the crystalline domains was different (Table 7). This size difference may have been due to a differential rate of cooling which afforded a crystalline structure in the OET better able to withstand a compressive force without irreversible deformation. Without being bound by

theory, the difference in the surface morphology and crystalline structure between the OET and InET may have be an important factor in the occurrence of creasing and/or wrinkling.

[00172] Table 7: X-Ray Data Summary for Sample Cups 1-6

Sample ID	Domain Size, Å		Percent Crystallinity, % (Determined by X-Ray)	% β -Phase = K-value*100
	α -Phase	β -Phase		
Cups 1-5 InET	121	183	61	37
Cups 1-5 OET	99	231	58	28
Extra talc ¹ - Inner	158	156	59	76
Extra talc - Outer	164	169	57	77
Sample B ² - Inner	145	Not Present	61	Not Applicable
Sample B - Outer	152	Not Present	59	Not Applicable

¹Extra talc = Cup of formula 5

²Sample B = Commercially available polypropylene cup

[00173] Crystalline domain size was sensitive to material formulation. As shown in Table 7, the alpha-phase crystal domain size for a sample with extra talc (2% talc) that exhibited creasing came out to be very large, *i.e.*, 158Å for InET and 164Å for OET, compared to the smaller alpha-phase crystal domain size for OET of Cups 1-5, which was measured at 99 Å. The InET surface of Cups 1-5 had an alpha-phase crystal domain size of 121Å. Cell size, polypropylene melting point, crystallization temperature, and degree of crystallinity (measured by differential scanning calorimetry and X-Ray analysis) of InET and OET foam surface were similar.

[00174] The OET surface of Cups 1-4 had the optimal cup appearance when OET was facing inside of the cup and had the best resistance to compression forces during cup formation. These cups also had the following unique combination of features:

- smallest alpha-phase crystal domain size;
- largest beta-phase crystal domain size; and

- K-value below 30 (Table 7).

[00175] Differential scanning calorimetry (DSC) analysis was conducted on a TA Instruments DSC 2910 using heat-cool-heat, 10 °C/min, under a nitrogen atmosphere. Differential scanning calorimetry unexpectedly revealed that, for all examples of cup formation described above, beta-crystallinity was absent from the DSC 2nd heat curve (Fig. 22), but could be identified via X-ray wide angle diffraction. For known conventional polypropylene-based foams, beta-crystallinity identified by X-ray wide angle diffraction would lead to an expectation of beta-crystallinity also being identified by differential scanning calorimetry. Thus, a feature of an insulative cellular polypropylene-based material in accordance with the present disclosure includes beta-crystallinity that is identifiable by wide angle X-ray diffraction but **not** by differential scanning calorimetry.

[00176] The beta-phase content (231 Å) was highest for the material that resulted in best performance (Table 7). Further study was conducted on the samples with comparable alpha domain size and comparable beta-phase domain size (all above 200 Å) and variable content of beta-phase as described by K-values. Unexpectedly, the relationship between the K-value and the ability to form a high surface quality cup without wrinkles was not proportional. There was a region of optimal K-values that resulted in excellent PP foam surface. The best cup appearance corresponded to the K-values ranging from 18 to 30, more preferably from 22 to 28.

Table 8.

Formulation	Crystal Domain Size, Å		Crystallinity, %	K Value, ratio	Visual appearance	Appearance scale (1 - bad, 5 - excellent)
	α -Phase	β -Phase				
2	152	207	62	9	Deep creases, cup is not usable	1
3	138	235	57	11	Rough surface, cup is not usable	1
4	142	205	56	15	Rough surface, cup is not usable	1
2	130	236	59	17	Creases, cup is not usable	2
2	149	230	58	25	Good quality cup, smooth surface	3 - 4
2	150	245	57	23	Best quality cup, smooth surface	4 - 5
1	99	231	58	28	Good cup quality, smooth surface	4
1	121	183	61	37	Creases, cup is not usable	2
5	158	156	59	77	Creases, cup is not usable	1
5	164	169	57	77	Creases, cup is not usable	1

[00177] Formulation 2:

81.45% Primary resin: high melt strength polypropylene Borealis WB140 HMS

15.0% Secondary resin: F020HC (Braskem)

0.05% Chemical blowing agent Clariant Hydrocerol™ CF-40E™

0.5% Nucleating agent: Talc

1.0% Colorant: Colortech 11933-19 TiO₂-PP

2.0% Slip agent: Ampacet™ 102823

[00178] Formulation 3:

81.45% Primary resin: high melt strength polypropylene Borealis WB140 HMS

15.0% Secondary resin: F020HC (Braskem)

0.05% Chemical blowing agent Clariant Hydrocerol™ CF-40™

0.5% Nucleating agent: Techmer PPM 16464 Silica

1.0% Colorant: Colortech 11933-19 TiO₂-PP

2.0% Slip agent: Ampacet™ 102823

[00179] Formulation 4:

81.45% Primary resin: high melt strength polypropylene Borealis WB140 HMS

15.0% Secondary resin: F020HC (Braskem)

0.05% Chemical blowing agent Clariant Hydrocerol™ CF-40E™

0.5% Nucleating agent: Heritage Plastics HT4HP Talc

1.0% Colorant: Colortech 11933-19 TiO₂-PP

2.0% Slip agent: Ampacet™ 102823

[00180] Formulation 5:

78.96% Primary resin: high melt strength polypropylene Borealis WB140 HMS

14.99% Secondary resin: F020HC (Braskem)

0.05% Chemical blowing agent Clariant Hydrocerol™ CF-40E™

2.0% Nucleating agent: Talc

1.0% Colorant: Colortech 11933-19 TiO₂-PP

3.0% Slip agent: Ampacet™ 102823

[00181] Crystal domain size of alpha-phase and beta-phase varied for the samples in Table 8, however there was an optimal K-values range of from about 20 to about 30 which corresponded to a best cup surface quality.

[00182] Example 5: Cell Density and Dimension Morphology

[00183] A study of foam cell morphology provided insight into the ability to form wrinkle- and crease-resistant insulative cellular polypropylene-based material. Wrinkle- and crease-resistance refers to lack of wrinkle formation and/or creasing during cup convolution or shaping of a sheet of insulative cellular polypropylene-based material.

[00184] Cell length and cell height were measured by scanning electron microscopy (SEM) for an extruded sheet of insulative cellular polypropylene-based material of the present disclosure (Sample A, using the formulation described above) and for a sheet of conventional polypropylene foam (Sample B). The microscopy image was evaluated visually, and representative cells were chosen for measurement of cell length and cell width. Such a method of cell size determination, based on measurements made at 3-10 points, was well known and is mostly used as a quality control tool in foam manufacturing. The purpose of the measurement was to find typical or average/representative cell size, not to provide cell size distribution. The aspect ratio was calculated by dividing cell length by cell width for the same specified direction (MD or CD).

[00185] Sample B (conventional foam) had a much higher MD cell aspect ratio than Sample A foam, *i.e.*, the cells of Sample B were long and narrow (Table 8). Sample B foam also possessed an aspect ratio below 2.0 in the CD direction, which was consistent with the cells of Sample B foam being long and narrow. In contrast, cells of Sample A foam had a much lower MD cell aspect ratio than cells of Sample B foam and an aspect ratio below 2.0 in the CD direction, thus indicative of cells with a more round shape.

[00186] Table 9: Cell Aspect Ratios

	Cell dimensions, mm	Sample B	Sample A
MD	Cell length	1.19	0.92
	Cell width	0.12	0.26
	MD Cell Aspect Ratio	9.92	3.54
CD	Cell length	0.30	0.52
	Cell width	0.20	0.27
	CD Cell Aspect Ratio	1.50	1.93

[00187] A coefficient of anisotropy was calculated as a ratio of cell width (or height) in MD to the same parameter in opposite direction (CD). As shown in Table 9, Sample B foam was highly anisotropic. In contrast, Sample A was not much different in MD vs. CD, and therefore has low coefficient of anisotropy.

[00188] Table 10: Coefficients of Anisotropy

Anisotropy Coefficient	Sample B	Sample A
MD cell length/CD cell length	4.0	1.8
MD cell width/CD cell width	0.6	1.0

Wrinkling of a cellular material with a fixed chemical composition, made in the identical extrusion process with the same processing parameters, was eliminated when die cut parts were oriented in CD direction providing a cell aspect ratio close to 1 and a coefficient of anisotropy close to 1.

[00189] Although only a number of exemplary embodiments of the present disclosure have been described in detail above, those skilled in the art will readily appreciate that many modifications are possible in the exemplary embodiments without materially departing from the

novel teachings and advantages. Accordingly, all such modifications are intended to be included within the scope of this disclosure as defined in the following claims.

[00190] As used in the specification and the appended claims, the singular forms “a,” “an” and “the” include plural referents unless the context clearly dictates otherwise. Ranges may be expressed herein as from “about” one particular value, and/or to “about” another particular value. When such a range is expressed, another embodiment includes from the one particular value and/or to the other particular value. Similarly, when values are expressed as approximations, by use of the antecedent “about,” it will be understood that the particular value forms another embodiment. It will be further understood that the endpoints of each of the ranges are significant both in relation to the other endpoint, and independently of the other endpoint.

[00191] “Optional” or “optionally” means that the subsequently described event or circumstance may or may not occur, and that the description includes instances where said event or circumstance occurs and instances where it does not.

[00192] Throughout the description and claims of this specification, the word “comprise” and variations of the word, such as “comprising” and “comprises,” means “including but not limited to,” and is not intended to exclude, for example, other additives, components, integers or steps. “Exemplary” means “an example of” and is not intended to convey an indication of a preferred or ideal embodiment. “Such as” is not used in a restrictive sense, but for explanatory purposes.

[00193] Disclosed are components that can be used to perform the disclosed methods and prepare the disclosed materials. These and other components are disclosed herein, and it is understood when combinations, subsets, interactions, groups, etc. of these components are disclosed that while specific reference of each various individual and collective combinations and permutation of these may not be explicitly disclosed, each is specifically contemplated and described herein, for all methods and materials. This applies to all aspects of this application including, but not limited to, steps in disclosed methods. Thus, if there are a variety of additional steps that can be performed, it is understood that each of these additional steps can be performed with any specific embodiment or combination of embodiments of the disclosed methods.

[00194] It will be apparent to those skilled in the art that various modifications and variations can be made without departing from the scope or spirit of the present disclosure. Other embodiments will be apparent to those skilled in the art from consideration of the

specification and practice disclosed herein. It is intended that the specification and examples be considered as exemplary only.

The following numbered paragraphs relate to particular embodiments of the present disclosure:

1. An insulative cellular polymeric material comprising a primary polypropylene resin, wherein beta-phase crystallinity is identifiable by wide angle X-ray diffraction and is not identifiable by differential scanning calorimetry.
2. The insulative cellular polymeric material of paragraph 1, further comprising a polypropylene secondary resin.
3. The insulative cellular polymeric material of paragraphs 1 or 2, further comprising a slip agent.
4. The insulative cellular polymeric material of paragraphs 1, 2 or 3, further comprising at least one nucleating agent.
5. The insulative cellular polymeric material of any preceding paragraph, wherein a beta-phase crystallinity peak is present in the diffraction pattern from diffraction of crystal reflections from a $\beta(300)$ plane.
6. An insulative cellular polymeric material comprising a primary polypropylene resin, wherein K-value is about 18 to about 30.
7. The insulative cellular polymeric material of paragraph 6, wherein K-value is about 22 to about 28.
8. The insulative cellular polymeric material of paragraphs 6 or 7, further comprising a polypropylene secondary resin.
9. The insulative cellular polymeric material of paragraphs 6, 7 or 8, further comprising a slip agent.
10. The insulative cellular polymeric material of any of paragraphs 6 to 9, further comprising at least one nucleating agent.
11. An insulative cellular polymeric material comprising a primary polypropylene resin, wherein the crystal domain size of alpha-phase polypropylene is less than about 100 Å and wherein the crystal domain size is determined by wide angle X-Ray diffraction.

12. An insulative cellular polymeric material comprising a primary polypropylene resin, wherein the crystal domain size of the beta-phase polypropylene is greater than about 190 Å and wherein the crystal domain size is determined by wide angle X-Ray diffraction.
13. The insulative cellular polymeric material of any preceding paragraph, wherein the insulative cellular polymeric material comprises any one of the formulations defined in any of the paragraphs appearing on pages 21 to 25.
14. A method of producing a wrinkle-resistant polymeric container comprising the steps of providing an extruded tube of a resin mixture comprising a primary polypropylene resin and cutting a shape in a cross-web direction (CD) from the extruded tube, wherein an outside-of-extruded-tube (OET) surface or layer faces the inside of the container.

Further particular embodiments of the disclosure are provided in the following numbered paragraphs:

15. An insulative cellular polypropylene-based material comprising
- i) a first polymer material comprising at least one high melt strength polypropylene homopolymer, and
 - ii) a second polymer material comprising at least one polymer selected from the group consisting of crystalline polypropylene homopolymer, impact polypropylene copolymer, and mixtures thereof,
- wherein the material is wrinkle-resistant or crease resistant.
16. The insulative cellular polypropylene-based material of paragraph 15, further comprising at least one nucleating agent.
17. The insulative cellular polypropylene-based material of paragraphs 15 or 16, further comprising at least one slip agent.
18. The insulative cellular polypropylene-based material of paragraphs 15, 16 or 17 having a cell aspect ratio in the machine direction of less than about 2.75.
19. The insulative cellular polypropylene-based material of paragraphs 15 to 18 having a cell aspect ratio in the machine direction of less than about 2.5.

20. The insulative cellular polypropylene-based material of paragraphs 15 to 19 having a cell aspect ratio in the cross direction of less than about 2.75.

21. The insulative cellular polypropylene-based material of paragraphs 15 to 20 having a cell aspect ratio in the cross direction of less than about 2.5.

22. The insulative cellular polypropylene-based material of paragraphs 15 to 21 having a cell aspect ratio in the cross direction of about 2.75 to about 3.75 and a cell density of about 800,000 cells/in³.

23. The insulative cellular polypropylene-based material of paragraphs 15 to 22 having a cell density of about 200,000 cells/in³ to about 700,000 cells/in³ and a cell aspect ratio in the machine direction of about 2.75 to about 3.5.

24. The insulative cellular polypropylene-based material of paragraphs 15 to 23 having a cell density of about 200,000 cells/in³ to about 900,000 cells/in³ and a cell aspect ratio in the cross direction of about 2.75 to about 4.0.

25. The insulative cellular polypropylene-based material of paragraphs 15 to 24 having a cell density of about 700,000 cells/in³ to about 2,000,000 cells/in³ and a cell aspect ratio in the machine direction of about 2.75 to about 4.5, wherein the material is micro-creasing or macro-creasing.

26. The insulative cellular polypropylene-based material of paragraphs 15 to 25 having a cell density of about 900,000 cells/in³ to about 2,000,000 cells/in³ and a cell aspect ratio in the cross direction of about 2.75 to about 4.5, wherein the material is micro-creasing or macro-creasing.

27. The insulative cellular polypropylene-based material of paragraphs 15 to 26 having a cell aspect ratio in the machine direction greater than 3.5.

28. The insulative cellular polypropylene-based material of paragraphs 15 to 27 having a cell density of about 800,000 cells/in³.

29. The insulative cellular polypropylene-based material paragraphs 15 to 28 having a cell density of about 200,000 cells/in³ to about 700,000 cells/in³.

30. The insulative cellular polypropylene-based material of paragraphs 15 to 29 having a cell density of about 200,000 cells/in³ to about 900,000 cells/in³.

31. The insulative cellular polypropylene-based material of paragraphs 15 to 30, wherein beta-phase crystallinity is identifiable by wide angle X-ray diffraction and is not identifiable by differential scanning calorimetry.

32. The insulative cellular polypropylene-based material of paragraphs 15 to 31, wherein a beta-phase crystallinity peak is present in the diffraction pattern from diffraction of crystal reflections from a $\beta(300)$ plane.

33. The insulative cellular polypropylene-based material of paragraphs 15 to 32, wherein K-value is about 18 to about 30.

34. The insulative cellular polypropylene-based material of paragraphs 15 to 33, wherein K-value is about 22 to about 28.

35. The insulative cellular polypropylene-based material of paragraphs 15 to 34, wherein the crystal domain size of alpha-phase polypropylene is less than about 100 Å and wherein the crystal domain size is determined by wide angle X-Ray diffraction.

36. The insulative cellular polypropylene-based material of paragraphs 15 to 35, wherein the crystal domain size of the beta-phase polypropylene is greater than about 190 Å and

wherein the crystal domain size is determined by wide angle X-Ray diffraction.

37. The insulative cellular polypropylene-based material of paragraphs 15 to 36, wherein the insulative cellular polymeric material comprises any one of the formulations defined in any of the paragraphs appearing on pages 21 to 25.

38. A process for producing a wrinkle-resistant polymeric container comprising the steps of

providing an extruded tube of a resin mixture comprising a primary polypropylene resin by extruding a formulation through extruder die lips at a die exit angle of 0° to about 60°,

wherein the formulation comprises

i) a first polymer material comprising at least one high melt strength polypropylene homopolymer,

ii) a second polymer material comprising at least one polymer selected from the group consisting of crystalline polypropylene homopolymer, impact polypropylene copolymer, and mixtures thereof,

iii) at least one nucleating agent, and

iv) at least one slip agent,

and then cutting a shape in a cross-web direction (CD) from the extruded tube, wherein an outside-of-extruded-tube (OET) surface or layer faces the inside of the container.

39. The process of paragraph 38, wherein the die exit angle is 0° to about 10°.

40. The process of paragraphs 38 or 39, wherein the die exit angle is about 10° to about 20°.

41. The process of paragraphs 38, 39, or 40, wherein the die exit angle is about 20° to about 30°.

42. The process of any of paragraphs 38 to 41, wherein the die exit angle is about 30° to about 40°.

43. The process of any of paragraphs 38 to 42, wherein the die exit angle is about 44°.

44. The process of any of paragraphs 38 to 43, wherein the die exit angle is about 40° to about 50°.

45. The process of any of paragraphs 38 to 44, wherein the die exit angle is about 50° to about 60°.

46. A process for producing a wrinkle-resistant polymeric container comprising the steps of

providing an extruded tube of a resin mixture comprising a primary polypropylene resin by extruding a formulation through extruder die lips,

wherein the formulation comprises

i) a first polymer material comprising at least one high melt strength polypropylene homopolymer,

ii) a second polymer material comprising at least one polymer selected from the group consisting of crystalline polypropylene homopolymer, impact polypropylene copolymer, and mixtures thereof,

iii) at least one nucleating agent, and

iv) at least one slip agent,

and then cutting a shape in a cross-web direction (CD) from the extruded tube, wherein an outside-of-extruded-tube (OET) surface or layer faces the inside of the container,

wherein cell dimensional attributes are according to $y = Ax^K$, wherein either x or y is cell density of the insulative cellular polypropylene-based material and the non-cell density variable is cell length, cell width, or cell wall thickness of the insulative cellular polypropylene-based material.

47. The process of paragraph 46, wherein power law constant A ranges from 9×10^8 to 1.3×10^9 , power law constant K ranges from -2.4 to -2.8, and x and y represent cell length and cell density, respectively.

48. The process of paragraphs 46 or 47, wherein power law constant A ranges from 2×10^8 to 4.3×10^8 , power law constant K ranges from -3.1 to -3.5, and x and y represent cell width and cell density, respectively.

49. The process of paragraphs 46, 47 or 48, wherein power law constant A ranges from 4×10^5 to 5×10^5 , power law constant K ranges from -2.8 to -3.2, and x and y represent cell wall thickness and cell density, respectively.

50. A process for producing a wrinkle-resistant polymeric container comprising the steps of

providing an extruded tube of a resin mixture comprising a primary polypropylene resin by extruding a formulation through an extruder nozzle including an inner die lip at an inner die lip angle of about 45° to about 60° and an outer die lip at an angle of about 35° degrees to about 55° ,

wherein the formulation comprises

i) a first polymer material comprising at least one high melt strength polypropylene homopolymer,

ii) a second polymer material comprising at least one polymer selected from the group consisting of crystalline polypropylene homopolymer, impact polypropylene copolymer, and mixtures thereof,

iii) at least one nucleating agent, and

iv) at least one slip agent,

and then cutting a shape in a cross-web direction (CD) from the extruded tube, wherein an outside-of-extruded-tube (OET) surface or layer faces the inside of the container.

51. The process of paragraph 50, wherein the inner die lip angle is about 48° to about 57° .

52. The process of paragraphs 50 or 51, wherein the inner die lip angle is about 49° .

53. The process of paragraphs 50, 51 or 52, wherein the outer die lip angle is about 40° to about 49° .

54. The process of paragraphs 50 to 53, wherein the outer die lip angle is about 41° .

55. The process of paragraphs 50 to 54, wherein the outer die lip angle is about 40° to about 49° .

56. The process of paragraphs 50 to 55, wherein the outer die lip angle is about 41°.

57. The process of any of paragraphs 38 to 56, wherein the formulation is as defined in any of the paragraphs appearing on pages 21 to 25.

Further particular embodiments of the disclosure are provided in the following numbered paragraphs:

58. A process for producing an insulative cellular polypropylene-based material comprising

extruding a formulation through extruder die lips at a die exit angle of about 61° to about 90° to produce an insulative cellular polypropylene-based material,

wherein the formulation comprises

i) a first polymer material comprising at least one high melt strength polypropylene homopolymer,

ii) a second polymer material comprising at least one polymer selected from the group consisting of crystalline polypropylene homopolymer, impact polypropylene copolymer, and mixtures thereof,

iii) at least one nucleating agent, and

iv) at least one slip agent.

59. The process of paragraph 58, wherein the die exit angle is about 70° to about 90°.

60. The process of paragraph 59, wherein the die exit angle is about 80° to about 90°.

61. The process of paragraph 60, wherein the die exit angle is about 85° to about 90°.

62. The process of claim paragraph 61, wherein the die exit angle is about 90°.

63. An insulative cellular polypropylene-based material comprising

i) a first polymer material comprising at least one high melt strength polypropylene homopolymer, and

ii) a second polymer material comprising at least one polymer selected from the group consisting of crystalline polypropylene homopolymer, impact polypropylene copolymer, and mixtures thereof,

wherein the material includes wrinkles or creases.

64. The insulative cellular polypropylene-based material of paragraph 63, further comprising at least one nucleating agent.

65. The insulative cellular polypropylene-based material of paragraph 63, further comprising at least one slip agent.

66. The insulative cellular polypropylene-based material of paragraphs 58-63 having a cell aspect ratio in the machine direction of greater than about 2.75.

67. The insulative cellular polypropylene-based material of paragraphs 58-63 having a cell aspect ratio in the machine direction of greater than about 3.0.

68. The insulative cellular polypropylene-based material of paragraphs 58-63 having a cell aspect ratio in the cross direction of greater than about 2.75.

69. The insulative cellular polypropylene-based material of paragraphs 58-63 having a cell aspect ratio in the cross direction of greater than about 3.0.

70. The insulative cellular polypropylene-based material of paragraphs 58-63 having a cell aspect ratio in the cross direction of greater than 2.75 and a cell density of greater than about 800,000 cells/in³.

71. The insulative cellular polypropylene-based material of paragraphs 58-63 having a cell density of less than 1,000,000 cells/in³ and a cell aspect ratio in the machine direction of greater than about 2.9.

72. The insulative cellular polypropylene-based material of paragraph 71 having the cell aspect ratio in the machine direction of greater than about 3.1.

73. The insulative cellular polypropylene-based material of paragraphs 58-63 having a cell density of less than about 1,200,000 cells/in³ and a cell aspect ratio in the cross direction of about 3.0 to about 4.5.

74. The insulative cellular polypropylene-based material of paragraphs 58-63 having a cell aspect ratio in the machine direction greater than 3.0.

75. The insulative cellular polypropylene-based material of paragraph 74 having a cell density of density of less than 1,200,000 cells/in³.

76. The insulative cellular polypropylene-based material of paragraph 74 having a cell aspect ratio in the cross direction greater than 2.75.

77. The insulative cellular polypropylene-based material of paragraph 76 having a cell density of density greater than $800,000 \text{ cells/in}^3$ and less than $1,500,000 \text{ cells/in}^3$.

78. A process for producing an insulative cellular polypropylene-based material comprising

extruding a formulation through extruder die lips to produce an insulative cellular polypropylene-based material,

wherein the formulation comprises

i) a first polymer material comprising at least one high melt strength polypropylene homopolymer,

ii) a second polymer material comprising at least one polymer selected from the group consisting of crystalline polypropylene homopolymer, impact polypropylene copolymer, and mixtures thereof,

iii) at least one nucleating agent, and

iv) at least one slip agent,

wherein cell dimensional attributes are according to $y = Ax^K$, wherein either x or y is cell density of the insulative cellular polypropylene-based material and the non-cell density variable is cell length, cell width, or cell wall thickness of the insulative cellular polypropylene-based material and

wherein the insulative cellular polypropylene-based material includes wrinkles or creases.

79. The process of paragraph 78, wherein power law constant A ranges from 9×10^8 to 1.3×10^9 , power law constant K ranges from -2.4 to -2.8, and x and y represent cell length and cell density, respectively and cell density is about $2 \times 10^5 \text{ cells/in}^3$ to about $7 \times 10^5 \text{ cells/in}^3$.

80. The process of paragraph 78, wherein power law constant A ranges from 2×10^8 to 4.3×10^8 , power law constant K ranges from -3.1 to -3.5, and x and y represent cell density and cell width, respectively and cell density is greater than about $1 \times 10^5 \text{ cells/in}^3$ and less than about $1 \times 10^6 \text{ cells/in}^3$.

81. The process of paragraph 78, wherein power law constant A ranges from 4×10^5 to 5×10^5 , power law constant K ranges from -2.8 to -3.2, and x and y represent cell density and cell wall thickness, respectively and cell density is greater than about $4 \times 10^5 \text{ cells/in}^3$ and less than about $8 \times 10^5 \text{ cells/in}^3$.

extruding a formulation through extruder die lips to produce an insulative cellular polypropylene-based material

82. The process of paragraphs 78-81, wherein the formulation is extruded through extruder die lips at a die exit angle of about 70° to about 90°.

83. The process of paragraph paragraphs 82, wherein the die exit angle is about 70° to about 90°.

84. The process of paragraph 83, wherein the die exit angle is about 80° to about 90°.

85. The process of paragraph 84, wherein the die exit angle is about 85° to about 90°.

86. The process of claim paragraph 85, wherein the die exit angle is about 90°.

87. The insulative cellular polypropylene-based material of paragraphs 83-86 having a cell aspect ratio in the machine direction of greater than about 2.75.

88. The insulative cellular polypropylene-based material of paragraphs 83-86 having a cell aspect ratio in the machine direction of greater than about 3.0.

89. The insulative cellular polypropylene-based material of paragraphs 83-86 having a cell aspect ratio in the cross direction of greater than about 2.75.

90. The insulative cellular polypropylene-based material of paragraphs 83-86 having a cell aspect ratio in the cross direction of greater than about 3.0.

91. The insulative cellular polypropylene-based material of paragraphs 83-86 having a cell aspect ratio in the cross direction of greater than 2.75 and a cell density of greater than about 800,000 cells/in³.

92. The insulative cellular polypropylene-based material of paragraphs 83-86 having a cell density of less than 1,000,000 cells/in³ and a cell aspect ratio in the machine direction of greater than about 2.9.

93. The insulative cellular polypropylene-based material of paragraph 91 having the cell aspect ratio in the machine direction of greater than about 3.1.

94. The insulative cellular polypropylene-based material of paragraphs 83-86 having a cell density of less than about 1,200,000 cells/in³ and a cell aspect ratio in the cross direction of about 3.0 to about 4.5.

95. The insulative cellular polypropylene-based material of paragraphs 83-86 having a cell aspect ratio in the machine direction greater than 3.0.

96. The insulative cellular polypropylene-based material of paragraph 95 having a cell density of density of less than 1,200,000 cells/in³.

97. The insulative cellular polypropylene-based material of paragraph 95 having a cell aspect ratio in the cross direction greater than 2.75.

98. The insulative cellular polypropylene-based material of paragraph 97 having a cell density of density greater than 800,000 cells/in³ and less than 1,500,000 cells/in³.

CLAIMS

1. A process for producing an insulative cellular polypropylene-based material comprising
extruding a formulation through extruder die lips at a die exit angle of 20° to about 60° to produce the insulative cellular polypropylene-based material,
wherein the formulation comprises
 - i) a first polymer material comprising at least one high melt strength polypropylene homopolymer,
 - ii) a second polymer material comprising at least one polymer selected from the group consisting of crystalline polypropylene homopolymer, impact polypropylene copolymer, and mixtures thereof,
 - iii) at least one nucleating agent, and
 - iv) at least one slip agent.
2. The process of claim 1, wherein the die exit angle is about 20° to about 30°.
3. The process of claim 1, wherein the die exit angle is about 30° to about 40°.
4. The process of claim 1, wherein the die exit angle is about 44°.
5. The process of claim 1, wherein the die exit angle is about 40° to about 50°.
6. The process of claim 1, wherein the die exit angle is about 50° to about 60°.
7. A process for producing an insulative cellular polypropylene-based material comprising
providing a formulation comprising
 - i) a first polymer material comprising at least one high melt strength polypropylene homopolymer,

ii) a second polymer material comprising at least one polymer selected from the group consisting of crystalline polypropylene homopolymer, impact polypropylene copolymer, and mixtures thereof,

iii) at least one nucleating agent, and

iv) at least one slip agent, and

extruding the formulation through an extruder die lip at a die exit angle of about 20° to about 60° to form a sheet of the material without surface indentations of greater than 5 microns when the sheet of the material is curved to form a round article.

8. An insulative cellular polypropylene-based material comprising

i) a first polymer material comprising at least one high melt strength polypropylene homopolymer, and

ii) a second polymer material comprising at least one polymer selected from the group consisting of crystalline polypropylene homopolymer, impact polypropylene copolymer, and mixtures thereof,

wherein the material has been extruded through an extruder die lip at a die exit angle of about 20° to about 60° so that surface indentations of greater than 5 microns are not present when a sheet of the material is curved to form a round article.

9. The insulative cellular polypropylene-based material of claim 8, further comprising at least one nucleating agent.

10. The insulative cellular polypropylene-based material of claim 8, further comprising at least one slip agent.

11. The insulative cellular polypropylene-based material of claim 8 having a cell aspect ratio in the machine direction of less than about 2.75.

12. The insulative cellular polypropylene-based material of claim 8 having a cell aspect ratio in the machine direction of less than about 2.5.

13. The insulative cellular polypropylene-based material of claim 8 having a cell aspect ratio in the cross direction of less than about 2.75.

14. The insulative cellular polypropylene-based material of claim 8 having a cell aspect ratio in the cross direction of less than about 2.5.

15. The insulative cellular polypropylene-based material of claim 14 having a cell aspect ratio in the machine direction of less than about 3.5.

16. The insulative cellular polypropylene-based material of claim 15 having a cell aspect ratio in the machine direction of less than about 3.25.

17. The insulative cellular polypropylene-based material of claim 16 having a cell aspect ratio in the machine direction of less than about 3.0.

18. The insulative cellular polypropylene-based material of claim 17 having a cell aspect ratio in the machine direction of less than about 2.75.

19. The insulative cellular polypropylene-based material of claim 18 having a cell aspect ratio in the machine direction of less than about 2.5.

20. The insulative cellular polypropylene-based material of claim 13 having a cell aspect ratio in the machine direction of less than about 3.5.

21. The insulative cellular polypropylene-based material of claim 20 having a cell aspect ratio in the machine direction of less than about 3.25.

22. The insulative cellular polypropylene-based material of claim 21 having a cell aspect ratio in the machine direction of less than about 3.0.

23. The insulative cellular polypropylene-based material of claim 22 having a cell aspect ratio in the machine direction of less than about 2.75.

24. The insulative cellular polypropylene-based material of claim 23 having a cell aspect ratio in the machine direction of less than about 2.5.

25. The insulative cellular polypropylene-based material of claim 8 having a cell aspect ratio in the cross direction of about 2.75 to about 3.75 and a cell density of about 800,000 cells/in³.

26. The insulative cellular polypropylene-based material of claim 8 having a cell density of about 200,000 cells/in³ to about 700,000 cells/in³ and a cell aspect ratio in the machine direction of about 2.75 to about 3.5.

27. The insulative cellular polypropylene-based material of claim 8 having a cell density of about 200,000 cells/in³ to about 900,000 cells/in³ and a cell aspect ratio in the cross direction of about 2.75 to about 4.0.

28. The insulative cellular polypropylene-based material of claim 8 having a cell density of about 700,000 cells/in³ to about 2,000,000 cells/in³ and a cell aspect ratio in the machine direction of about 2.75 to about 4.5, wherein the material is micro-creasing or macro-creasing.

29. The insulative cellular polypropylene-based material of claim 8 having a cell density of about 900,000 cells/in³ to about 2,000,000 cells/in³ and a cell aspect ratio in the cross direction of about 2.75 to about 4.5, wherein the material is micro-creasing or macro-creasing.

30. The insulative cellular polypropylene-based material of claim 8 having a cell aspect ratio in the machine direction greater than 3.5.

31. The insulative cellular polypropylene-based material of claim 8 having a cell density of about 800,000 cells/in³.

32. The insulative cellular polypropylene-based material of claim 8 having a cell density of about 200,000 cells/in³ to about 700,000 cells/in³.

33. The insulative cellular polypropylene-based material of claim 8 having a cell density of about 200,000 cells/in³ to about 900,000 cells/in³.

34. A process for producing an insulative cellular polypropylene-based material comprising

providing a formulation comprising

- i) a first polymer material comprising at least one high melt strength polypropylene homopolymer,
- ii) a second polymer material comprising at least one polymer selected from the group consisting of crystalline polypropylene homopolymer, impact polypropylene copolymer, mixtures thereof,
- iii) at least one nucleating agent, and
- iv) at least one slip agent, and

extruding the formulation through an extruder nozzle including an inner die lip at an inner die lip angle of about 45° to about 60° and an outer die lip at an angle of about 35° to about 55° to produce the insulative cellular polypropylene-based material without surface

indentations of greater than 5 microns when the sheet of the material is curved to form a round article.

35. The process of claim 34, wherein the inner die lip angle is about 48° to about 57° .

36. The process of claim 35, wherein the inner die lip angle is about 49° .

- 37. The process of claim 36, wherein the outer die lip angle is about 40° to about 49°.
- 38. The process of claim 37, wherein the outer die lip angle is about 41°.
- 39. The process of claim 34, wherein the outer die lip angle is about 40° to about 49°.
- 40. The process of claim 39, wherein the outer die lip angle is about 41°.