

**POLYMER PROCESSING AIDS BASED ON POLYDIMETHYLSILOXANE
AND POLYETHYLENE GLYCOL**

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of U.S. Provisional Application Serial Nos. 63/609,122 filed December 12, 2023, and 63/609,520 filed December 13, 2023, the contents of which are incorporated in their entirety herein.

TECHNICAL FIELD

[0002] The present disclosure generally relates to polymer processing aids.

BACKGROUND

[0003] Plastics are used for a wide range of industrial applications, including packaging, construction, and wire and cable. However, many plastics suffer from melt fracture during extrusion, which is a phenomenon where the surface of the plastic becomes distorted with undulations or irregularities. Some types of melt fracture, such as sharkskin melt fracture, impact the surface of the plastic by causing irregular and sometimes scaly surface texture, which may reduce the glossiness of the surface.

[0004] Conventional processes for preventing melt fracture in polyethylene include using fluoropolymer-based processing aids. However, concerns that fluorinated chemical compounds may be persistent in the environment have spurred restrictions on these materials, including fluoropolymer-based processing aids. Accordingly, a need exists for improved formulations and methods that may reduce melt fracture, while also alleviating concerns about environmental persistence.

SUMMARY

[0005] Embodiments of the present disclosure address these and other needs by providing a method of removing melt fracture during extrusion, the method including blending ethylene-based

polymer with a polymer processing aid (PPA) to remove the melt fracture during extrusion, wherein the PPA includes polydimethylsiloxane (PDMS) and polyethylene glycol. In some embodiments, the ethylene-based polymer has a melt index (I_2) of less than 2.0 dg/min. The PDMS may be a non-functionalized PDMS. The PDMS may have a kinematic viscosity range of 4,000 to 100,000 cSt. The polyethylene glycol may have an average molecular weight (MW) of 1,000 to 10,000 g/mol. The ratio by weight of PDMS may be from 95:5 to 65:35. Without being limited by theory, the PDMS and polyethylene glycol work in combination as a processing aid to reduce melt fracture.

[0006] According to one or more embodiments of the present disclosure, an article may be produced by the above method.

[0007] Additional features and advantages will be set forth in the detailed description that follows and, in part, will be readily apparent to those skilled in the art from that description or recognized by practicing the embodiments described herein, including the detailed description which follows in addition to the claims.

[0008] It is to be understood that both the foregoing general description and the following detailed description describe various embodiments and are intended to provide an overview or framework for understanding the nature and character of the claimed subject matter.

DETAILED DESCRIPTION

[0009] Reference will now be made in detail to embodiments of methods of removing melt fracture during extrusion including blending ethylene-based polymer having a melt index (I_2) of less than 2.0 dg/min with a polymer processing aid (PPA) to remove the melt fracture during extrusion, wherein the PPA includes non-functionalized polydimethylsiloxane (PDMS) having a kinematic viscosity range of 4,000 to 100,000 cSt; and polyethylene glycol (PEG) having an average molecular weight (MW) of 1,000 to 10,000 g/mol, wherein the ratio by weight of PDMS to PEG is from 95:5 to 65:35. It is contemplated that additional additives may also be included; however, the PPA is essentially free of fluoropolymer.

[0010] Without being bound by theory, the polyethylene glycol and the PDMS may interact with the metal surface of the extruder and with each other such that a lubricating multi-layer is formed between the metal surface and the polymer melt, thus reducing melt fracture.

[0011] As used in this disclosure, the term “polymer” may refer to a polymeric compound prepared by polymerizing monomers, whether of the same or a different type. The generic term polymer thus embraces the term “homopolymer,” usually employed to refer to polymers prepared from only one type of monomer as well as “copolymer,” which refers to polymers prepared from two or more different monomers. The term “interpolymer,” as used herein, refers to a polymer prepared by the polymerization of at least two different types of monomers. The generic term interpolymer thus includes copolymers and polymers prepared from more than two different types of monomers, such as terpolymers.

[0012] “Blend,” “polymer blend,” and like terms mean a composition of two or more polymers. Such a blend may or may not be miscible. Such a blend may or may not be phase separated. Such a blend may or may not contain one or more domain configurations, as determined from transmission electron spectroscopy, light scattering, x-ray scattering, and any other method known in the art. Blends are not laminates, but one or more layers of a laminate may contain a blend. Such blends can be prepared as dry blends, formed *in situ* (e.g., in a reactor), melt blends, or using other techniques known to those of skill in the art.

[0013] As used in this disclosure, the term “polyethylene” or “ethylene-based polymer” may refer to polymers comprising greater than 50% by mole of units which have been derived from ethylene monomer. This includes polyethylene homopolymers or copolymers (meaning units derived from two or more comonomers). Common forms of ethylene-based polymer known in the art include Low Density Polyethylene (LDPE); Linear Low Density Polyethylene (LLDPE); Ultra Low Density Polyethylene (ULDPE); Very Low Density Polyethylene (VLDPE); single-site catalyzed Linear Low Density Polyethylene, including both linear and substantially linear low density resins (m-LLDPE); Medium Density Polyethylene (MDPE); and High Density Polyethylene (HDPE).

[0014] The term “LLDPE” includes both resin made using the traditional Ziegler-Natta catalyst systems and chromium-based catalyst systems as well as single-site catalysts, including, but not

limited to, bis -metallocene catalysts (sometimes referred to as “m- LLDPE”), constrained geometry catalysts (CGC), and molecular catalysts. Resins include linear, substantially linear, or heterogeneous polyethylene copolymers or homopolymers. LLDPEs contain less long chain branching than LDPEs and includes the substantially linear ethylene polymers, which are further defined in U.S. Patent 5,272,236, U.S. Patent 5,278,272, U.S. Patent 5,582,923 and U.S. Patent 5,733,155; the homogeneously branched linear ethylene polymer compositions such as those in U.S. Patent No. 3,645,992; the heterogeneously branched ethylene polymers such as those prepared according to the process disclosed in U.S. Patent No. 4,076,698; and/or blends thereof (such as those disclosed in US 3,914,342 or US 5,854,045). The LLDPEs can be made via gas-phase, solution-phase, or slurry polymerization or any combination thereof, using any type of reactor or reactor configuration known in the art.

[0015] As used herein, “fluoropolymer” refers to polymeric compounds comprising fluorine and is intended to be interpreted broadly so as to include what might be referred to as oligomeric species. As a non-limiting example, the fluoropolymer may comprise molecules containing at least three, at least four, at least five, or at least six fluorine containing units.

[0016] As used herein, “essentially free of” means comprising less than 50 ppmw.

[0017] As used herein, “melt fracture” refers to the formation of defects on a polymeric extrudate under various processing conditions. The defects may be any deviation from a smooth, glossy, regular extrudate.

[0018] As used herein, “surging” refers to instability of melt pressure and flow rate at the discharge end of an extruder.

[0019] As used herein, “parts per million weight” or “ppmw” refers to parts per million by weight.

[0020] As used herein, “polymer melt” refers to polymers or polymer blends that are at temperatures above their glass transition temperature (i.e., the temperature below which the physical properties of the polymers change to those of a glassy or crystalline state, and usually

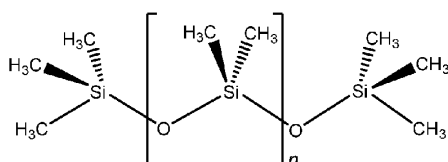
above their melting temperature). The polymer melts may present as highly viscous liquids, and may possess non-Newtonian or viscoelastic natures.

[0021] In various embodiments, a method of removing melt fracture during extrusion includes blending ethylene-based polymer with a polymer processing aid (PPA) to remove melt fracture during extrusion. In one or more embodiments, the PPA is dry blended with the ethylene-based polymer. In one or more embodiments, the PPA or a masterbatch thereof is melt blended with the ethylene-based polymer.

[0022] Various compositions are considered suitable for the ethylene-based polymer. In one or more embodiments, the ethylene-based polymer may comprise linear low density polyethylene (LLDPE). In embodiments, the ethylene-based polymer may comprise a melt index (I_2) of less than 2.0 dg/min as measured according to ASTM D-1238 (190° C / 2.16 Kg). In embodiments, the ethylene-based polymer may comprise a melt index of from 0.05 to 2.0 dg/10 mins, from 0.05 to 1.8 dg/10 mins, from 0.05 to 1.6 dg/10 mins, from 0.05 to 1.5 dg/10 mins, 0.1 to 2.0 dg/10 mins, from 0.1 to 1.8 dg/10 mins, from 0.1 to 1.6 dg/10 mins, from 0.1 to 1.5 dg/10 mins, from 0.1 to 1.4 dg/10 mins, 0.5 to 2.0 dg/10 mins, from 0.5 to 1.8 dg/10 mins, from 0.5 to 1.6 dg/10 mins, from 0.5 to 1.5 dg/10 mins, from 0.5 to 1.4 dg/10 mins, 1.0 to 2.0 dg/10 mins, from 1.0 to 1.8 dg/10 mins, from 1.0 to 1.6 dg/10 mins, from 1.0 to 1.5 dg/10 mins, or from 1.0 to 1.4 dg/10 mins. In further embodiments, the ethylene-based polymer may comprise a density from 0.850 to 0.950 g/cc, from 0.875 to 0.925 g/cc, from 0.890 to 0.915 g/cc, or from 0.895 to 0.910 g/cc.

[0023] In one or more embodiments, the polyethylene glycol may have an average molecular weight (MW) of 1,000 to 15,000 grams per mol (g/mol). In embodiments, the polyethylene glycol may have an average MW of from 1,000 to 15,000 g/mol, 2,500 to 15,000 g/mol, 5,000 to 15,000 g/mol, 7,500 to 15,000 g/mol, 1,000 to 10,000 g/mol, 2,500 to 10,000 g/mol, 5,000 to 10,000 g/mol, or 7,500 to 10,000 g/mol. Without being bound by theory, it is believed that if the molecular weight of the polyethylene glycol is below 1,000 g/mol, surging may occur during processing of the blown film; if the molecular weight of the polyethylene glycol is above 15,000 g/mol, the resulting blown film may be hazy. Furthermore, it is believed that using a polyethylene glycol with a molecular weight greater than 15,000 g/mol may diminish the ability of the PPA to clear melt fracture.

[0024] “Polydimethylsiloxane” (“PDMS”) is a polymeric organosilicon compound with the following general Formula (I) wherein n is the number of repeating monomer $[\text{SiO}(\text{CH}_3)_2]$ units, and n is greater than or equal to 2, or from 2 to 20,000:



Formula (I)

[0025] In one or more embodiments, the PDMS may be a non-functionalized PDMS. A “non-functionalized PDMS” is a PDMS in which the methyl groups of Formula (I) are not substituted with substituents. In one or more embodiments, the PDMS may comprise a kinematic viscosity of at least 4,000 to 100,000 centistokes (cSt). In embodiments, the PDMS may comprise a kinematic viscosity from 4,000 to 100,000 cSt, 5,000 to 100,000 cSt, 7,500 to 100,000 cSt, 10,000 to 100,000 cSt, 25,000 to 100,000 cSt, 50,000 to 100,000 cSt, 75,000 to 100,000 cSt, 4,000 to 75,000 cSt, 5,000 to 75,000 cSt, 7,500 to 75,000 cSt, 10,000 to 75,000 cSt, 25,000 to 75,000 cSt, 50,000 to 75,000 cSt, 5,000 to 50,000 cSt, 7,500 to 50,000 cSt, 10,000 to 50,000 cSt, 25,000 to 50,000 cSt, 5,000 to 25,000 cSt, 7,500 to 25,000 cSt, 10,000 to 25,000 cSt, 5,000 to 10,000 cSt, 7,500 to 10,000 cSt, or 5,000 to 7,500 cSt.

[0026] Moreover, the ratio by weight of PDMS to polyethylene glycol may be from 95:5 to 65:35. In embodiments, the ratio by weight of PDMS to polyethylene glycol may be from 95:5 to 65:35, from 90:10 to 65:35, from 80:20 to 65:35, from 70:30 to 65:35, from 90:10 to 70:30, or from 80:20 to 70:30. Without being bound by theory, it is believed that a ratio by weight of PDMS to polyethylene glycol of from 95:5 to 65:35 modifies the viscosity of the polyethylene to help reduce melt fracture.

[0027] In one or more embodiments, the PPA may be essentially free of fluoropolymer. In embodiments, the PPA may comprise less than 50 ppmw, less than 40 ppmw, less than 30 ppmw, less than 20 ppmw, less than 10 ppmw, less than 5 ppmw, less than 2 ppmw, or less than 1 ppmw fluoropolymer.

[0028] Further optional additives are contemplated for the PPA. In some embodiments, the PPA may include one or more other additives. Non limiting examples of suitable other additives include antioxidants, antistatic agents, stabilizing agents, nucleating agents, colorants, pigments, ultra violet (UV) absorbers or stabilizers, flame retardants, compatibilizers, plasticizers, fillers, processing aids, antifog additives, crosslinking agents (e.g., peroxides), and combinations thereof. All individual values and subranges from 0 to 3 wt.% are included and disclosed herein; for example, the total amount of additives in the polymer blend can be from a lower limit of 0.5, 1, 1.5, 2, 2.5, 3, 3.5, 4, or 4.5 wt.% to an upper limit of 1, 2, 3, 4, or 5 wt.%.

[0029] Various process procedures are considered suitable for producing the PPA. For example, it is contemplated to add the PPA components in various orders. In some embodiments, the PPA may be melt blended directly into the ethylene-based polymer. In one or more embodiments, the PPA may be added to the ethylene-based polymer via a masterbatch. In embodiments, generating a masterbatch may comprise compounding a polyethylene resin with the PPA. The masterbatch may be combined with a base resin to reduce melt fracture in the base resin in an extruder to fabricate a finished article, for example, a blown film, cable, wire, tube, or pipe. The masterbatch may be melt-blended or dry-blended with the base resin before or during extrusion to fabricate an article, for example, a blown film, cable, wire, tube, or pipe, with reduced melt fracture. The base resin may include ethylene-based polymer, for example, LLDPE.

[0030] In various embodiments, the PPA may be provided in a polymer masterbatch. In one or more embodiments, the polymer masterbatch may include from 1 to less than 15 weight percent (wt.%) PPA. In some embodiments, the polymer master batch may include from 1 to less than 15 wt.%, from 2 to less than 15 wt.%, from 3 to less than 15 wt.%, from 5 to less than 15 wt.%, from 10 to less than 15 wt.%, from 1 to 14 wt.%, from 2 to 14 wt.%, from 3 to 14 wt.%, from 5 to 14 wt.%, from 10 to 14 wt.%, from 1 to 12 wt.%, from 2 to 12 wt.%, from 3 to 12 wt.%, from 5 to 12 wt.%, from 10 to 12 wt.%, from 1 to 10 wt.%, from 2 to 10 wt.%, from 3 to 10 wt.%, or from 5 to 10 wt.% PPA.

[0031] In one or more embodiments, the PPA may remove melt fracture in less than or equal to 120 minutes (min). In embodiments, the PPA may remove melt fracture in less than 200 min, less than 175 min, less than 150 min, less than 125 min, less than or equal to 120 min, less than

or equal to 110 min, less than or equal to 100 min, less than or equal to 90 min, less than or equal to 80 min, less than or equal to 70 min, less than or equal to 60 min, less than or equal to 50 min, less than or equal to 40 min, or less than or equal to 30 min.

[0032] ARTICLES

[0033] In one or more embodiments, an article may be produced from the base resin and the PPA described herein. The articles may include films, for example, blown films. The films may be monolayer or multilayer films. Articles, which incorporate film, may include non-rigid packages, such as flexible packages, pouches, stand-up pouches, and the like. The articles may also include rigid packages, for example, conduits, wires, cables, and the like. Articles may also include tubes or pipes.

[0034] In various embodiments, an article, for example, a blown film, produced according to the method disclosed and described herein, may include from 120 to 800 ppm polyethylene glycol. In some embodiments, an article, for example, a blown film, produced according to the method disclosed and described herein may include from 120 to 800 ppm, 150 to 800 ppm, 200 to 800 ppm, 400 to 800 ppm, 600 to 800 ppm, 120 to 600 ppm, 150 to 600 ppm, 200 to 600 ppm, 400 to 600 ppm, 120 to 400 ppm, 150 to 400 ppm, 200 to 400 ppm, 120 to 200 ppm, or from 150 to 200 ppm polyethylene glycol. Without being bound by theory, it is believed that using a concentration of polyethylene glycol that results in a concentration of 800 ppm or less in the resulting article may diminish surging during processing. However, it is believed that using a concentration of polyethylene glycol that results in a concentration of less than 120 ppm in the resulting article may diminish the ability of the PPA to clear melt fracture.

[0035] In various embodiments, an article, for example, a blown film, produced according to the method disclosed and described herein, may include at least 500 ppm PPA. In some embodiments, an article, for example, a blown film, produced according to the method disclosed and described herein may include from 500 to 10,000 ppm, from 1,000 to 10,000 ppm, from 2,000 to 10,000 ppm, from 3,000 to 10,000 ppm, from 4,000 to 10,000 ppm, from 5,000 to 10,000 ppm, from 6,000 to 10,000 ppm, from 500 to 9,000 ppm, from 1,000 to 9,000 ppm, from 2,000 to 9,000 ppm, from 3,000 to 9,000 ppm, from 4,000 to 9,000 ppm, from 5,000 to 9,000 ppm, from 6,000 to 9,000 ppm, from 500 to 8,000 ppm, from 1,000 to 8,000 ppm, from 2,000 to 8,000 ppm, from

3,000 to 8,000 ppm, from 4,000 to 8,000 ppm, from 5,000 to 8,000 ppm, from 6,000 to 8,000 ppm, from 500 to 7,000 ppm, from 1,000 to 7,000 ppm, from 2,000 to 7,000 ppm, from 3,000 to 7,000 ppm, from 4,000 to 7,000 ppm, from 5,000 to 7,000 ppm, from 500 to 5,000 ppm, from 1,000 to 5,000 ppm, from 2,000 to 5,000 ppm, from 3,000 to 5,000 ppm, or from 4,000 to 5,000 ppm, PPA.

[0036] TEST METHODS

[0037] Melt Index (190 °C, 2.16 kg, “I₂”) Test Method: ASTM D 1238-13, *Standard Test Method for Melt Flow Rates of Thermoplastics by Extrusion Plastometer*, using conditions of 190 °C/2.16 kilograms (kg). Results were reported in units of grams eluted per 10 minutes (dg/10 min.)

[0038] Average molecular weight (MW) of the PEG may be determined according to ASTM D4274, the entire protocol of which is hereby incorporated by reference.

[0039] Kinematic viscosity was measured for the PDMS using an MCR 301 rheometer commercially available from Anton-Paar. The rheometer was fitted with a 25 millimeter (mm) stainless steel cone-in-plate fixture at an operative temperature of 25 °C. Steady shear measurements at shear rates ranging from 0.1 to 500 s⁻¹ were performed. Prior to each measurement, the material was allowed to equilibrate for at least 5 min. The kinematic viscosity is the average viscosity over the shear rate from 0.1-10 s⁻¹.

EXAMPLES

[0040] The following Examples are offered by way of illustration and are presented in a manner such that one skilled in the art should recognize are not meant to be limiting to the present disclosure as a whole or to the appended claims.

[0041] The following compositions were used in the Examples below.

[0042] LLDPE-1 has a melt index (I₂) of 0.5 g/10 mins. and a density of 0.905 g/cc.

[0043] LLDPE-2 has an I₂ of 0.5 g/10 mins. and a density of 0.920 g/cc.

[0044] CARBOWAX™ 8000 PEG, which is commercially available from Dow Inc., has an average molecular weight of 8000 g/mol.

[0045] PDMS-1, which is a non-functionalized polydimethylsiloxane silanol, has a kinematic viscosity of 60,000 cSt.

[0046] DOWLEX™ 2047G, which is a polyethylene resin, has a density of 0.917 g/cm³ and an I₂ of 2.3 g/10 mins.

[0047] EXAMPLE 1 – Production of LLDPE-1 resin

[0048] LLDPE-1 was prepared according to Inventive Example 1 described in US. Patent Number 8,372,931, the entirety of which is hereby incorporated by reference.

[0049] EXAMPLE 2 – Production of LLDPE-2 resin

[0050] LLDPE-2 was prepared by first creating the resin of Composition 1 described in U.S. Patent Number 10,308,741, the entirety of which is hereby incorporated by reference. The polymer was melt blended with several additives using a single screw extruder. The additives were added as masterbatches in pellet form. The masterbatches were made of a LLDPE with a melt index of 2.3 grams per 10 minutes and a density of 0.917 grams per cubic centimeter. The additives included 5100 ppm talc, 550 ppm primary antioxidant, 1000 ppm secondary antioxidant, 918 ppm erucamide, 1120 ppm PDMS-1, and 480 ppm PEG 8000. The melt temperature for the extrusion and melt mixing process was approximately – 220 degrees Celsius. The molten polymer was then pelletized in an underwater pelletizer.

[0051] EXAMPLE 3 – Production of PPA masterbatch

[0052] An additive masterbatch containing PDMS-1 and CARBOWAX™ 8000 PEG was made in a ZE 42mm co-rotating twin screw extruder (TSE) with 48 L/D from Krauss Maffei. DOWLEX™ 2047G, which was used as a base resin, was fed into the main extruder feed hopper using a K-Tron T35 pellet feeder, the CARBOWAX™ 8000 PEG powder was also fed in the main feed hopper using a K-Tron T20 powder feeder, and the liquid PDMS-1 was injected using a

Zennith pump (Zenith H series 5704, 2.92 cc/rev) into barrel # 7 ($L/D = 26$). The polymer melt was extruded using a 3.2mm, 6 hole die and was pelletized using a MAP-6 Gala pelletizer. The process conditions are presented in Table 3.

Table 3: Masterbatch Production Process Conditions

Process Variable	Unit	Value
Total throughput	Lb/h	200.0
DOWLEX™ 2047G	Lb/h	184.0
PDMS-1	Lb/h	11.2
PDMS-1	Lb/h	4.8
Screw Speed	RPM	250
Extruder Torque	%	55
Specific energy	kW.h/lb	0.097
Extruder Temperature Profile		
Barrel 1	°C	25
Barrel 2	°C	80
Barrel 3 – Barrel 11	°C	180
Die Temperature	°C	200
Water Temperature	°C	45
Pellet count	#/g	32

[0053] EXAMPLE 4 – Production of Blown Films

[0054] Monolayer PE blown films were prepared using a blown film line equipped with a single-screw extruder (SSE). The SSE was a 3.5 inch Davis Standard Barrier II Screw. The SSE had a flighted length (L) of 1 inch, resulting in a ratio of the flighted length of the screw to its outside diameter (L/D) of 14, and an outer diameter to inner diameter (Do/Di) ratio of 1.55. The base resin, which was LLDPE-1, without any processing aid, was added to the feed hopper of the SSE until the flow was stabilized, which led to melt fracture in the film. Then, a PPA masterbatch prepared according to Example 3 was dry blended with the base resin and fed in the same hopper of the SSE to create blown films with polymer processing aid (PPA). The percent PPA in each specific masterbatch, as well as the fractions of PDMS and PEG in the PPA, and the percentage of the masterbatch in the final resin of each formulation are provided in Table 4.

Table 4: Composition by Film Number

Film Number	wt.% PPA in MB	PDMS fraction of PPA (wt.%)	PEG fraction of PPA (wt.%)	MB Loading in final resin (wt.%)
C1	0	0	0	0
C2	15	100	0	3.4
C3	8	100	0	5
C4	8	100	0	4
C5	8	70	30	4.0
I1	8	90	10	2.0
I2	8	90	10	4.0
I3	8	85	15	2.0
I4	8	80	20	2.0
I5	8	70	30	2.0
I6	8	70	30	3.0

[0055] The blown film processing conditions for the films in Table 4 are listed in Table 5.

Table 5: Processing Conditions

Film Number	Avg. Extruder Speed (RPM)	Polymer Rate (lb/h)	Specific Rate (lb/h/rpm)	Rate Loss (%)
C1	49	250	5.10	0.00
C2	65	250	3.85	24.62
C3	49.4	250	5.06	0.81
C4	49.2	250	5.08	0.41
C5	76.5	250	3.27	35.95
I1	46.9	250	5.33	-4.48
I2	48.1	250	5.20	-1.87
I3	49.6	250	5.04	1.21
I4	46.3	250	5.40	-5.83
I5	49.7	250	5.03	1.41
I6	49	250	5.10	0.00

[0056] The concentration of the total PPA, the PDMS, and the PEG in the resulting blown film is shown in Table 6.

[0057] A timer was started when each formulation was introduced in the extruder after the process was stabilized. If melt fracture was not cleared after 60 minutes, the timer was stopped.

The results are shown in Table 6. After every formulation, the extruder was purged with the base resin until the melt fracture was fully re-established; confirmed visually as well by the stabilization of the processing conditions (extruder torque, pressure).

[0058] During production, the blown film process was monitored for surging. The polymer flow rate for the blown film process was kept constant at 250 lb/h. For a polymer without any PPA, the screw speed to achieve 250 lb/h is typically between 44-51 rpm. The screw speed was adjusted if the polymer throughput rate of 250 lb/h was not achieved and was recorded. Higher screw speed is an indication of surging in the single screw extruder. In addition to that the polymer melt pressure was also continuously monitored at the die exit. For the non-surging polymer system in this blown film process, the melt pressure is very steady with a standard deviation below 50 psi. If the melt pressure standard deviation is above 50 psi, significant surging was observed. The presence or absence of surging is shown in Table 6.

Table 6: Concentration of PPA, PDMS, and PEG in Blown Film

Film Number	PPA in film (ppm)	PDMS in film (ppm)	PEG in film (ppm)	Melt Fracture Cleared in 60 Minutes	Surging Observed
C1	0	0	0	NO	NO
C2	5100	5100	0	YES	YES
C3	4000	4000	0	NO	NO
C4	3200	3200	0	NO	NO
C5	3200	2240	960	YES	YES
I1	1600	1440	160	YES	NO
I2	3200	2880	320	YES	NO
I3	1600	1360	240	YES	NO
I4	1600	1280	320	YES	NO
I5	1600	1120	480	YES	NO
I6	2400	1680	720	YES	NO

[0059] EXAMPLE 5 – Production of Blown Films

[0060] Monolayer PE blown films were prepared using the SSE of Example 4. The identity of the base resin, any additional PPA, and the PDMS and PEG fractions of the PPA are shown in Table 7.

Table 7: Composition by Film Number

Film Number	Base Resin Blended with MB	Additional PPA	PDMS fraction of PPA (wt.%)	PEG fraction of PPA (wt.%)
C6	LLDPE -2	1.5 wt%	70	30
C7	LLDPE -2	2 wt%	70	30
I7	LLDPE -2	None	70	30
I8	LLDPE -2	1.5 wt%	90	10

[0061] The processing conditions, including the average extruder speed, the polymer rate, the specific rate, and the rate loss are shown in Table 8.

Table 8: Processing Conditions

Formulation Number	Avg. Extruder RPM	Polymer Rate (lb/h)	Specific Rate (lb/h/rpm)	Rate Loss (%)
C6	56.87	250	4.40	13.84
C7	60.95	250	4.10	19.61
I7	47.7	250	5.24	-2.73
I8	44.6	250	5.61	-9.87

[0062] The concentration of the total PPA, the PDMS, and the PEG in the blown film was as shown in Table 9.

[0063] A timer was started when each formulation was introduced in the extruder after the process was stabilized. If melt fracture was not cleared after 30 minutes, the timer was stopped. The results are shown in Table 9. After every formulation, the extruder was purged with the base resin until the melt fracture was fully re-established; confirmed visually as well by the stabilization of the processing conditions (extruder torque, pressure).

[0064] During production, the blown film was monitored for surging. The polymer flow rate for the blown film process was kept constant at 250 lb/h. For a polymer without any PPA, the screw speed to achieve 250 lb/h is typically between 44-51 rpm. The screw speed was adjusted if the polymer throughput rate of 250 lb/h was not achieved and was recorded. Higher screw speed is an indication of surging in the single screw extruder. Additionally, the polymer melt pressure was continuously monitored at the die exit. For the non-surging polymer system in this blown film process, the melt pressure is very steady with a standard deviation below 50 psi. If the melt

pressure standard deviation is above 50 psi, significant surging was observed. The presence or absence of surging is shown in Table 9.

Table 9: Concentration of PPA, PDMS, and PEG in Blown Film

Formulation Number	PPA in film (ppm)	PDMS in film (ppm)	PEG in film (ppm)	Melt Fracture Cleared in 60 Minutes	Surging Observed
C6	2800	1960	840	YES	YES
C7	3200	2240	960	YES	YES
I7	1600	1120	480	YES	NO
I8	2800	2200	600	YES	NO

[0065] The average pressure fluctuation and standard deviation from the average pressure for formulations C6, C7, I8, and I9 were determined and recorded in Table 10.

Table 10: Surging for Various Formulations

Formulation Number	Surging Observed	Pressure fluctuation, avg (psi)	Pressure fluctuation, Std Dev (psi)
C6	YES	4936	76
C7	YES	4691	158
I7	NO	5622	43
I8	NO	5338	26

[0066] As shown in Table 6, formulations I1-I6, which all included blown films that had a final concentration of 800 ppm or less, all cleared the melt fracture in less than 60 minutes. Conversely, formulations C1, C3, and C4, which did not include any PEG, failed to clear the melt fracture within 60 minutes, but did not cause surging during processing. However, formulation C2, which also did not include any PEG, but included 15 wt.% PPA, successfully cleared the melt fracture within 60 minutes, but caused surging during processing. Additionally, formulation C5, which included 960 ppm PEG, successfully cleared the melt fracture within 60 minutes, but caused surging during processing, thus demonstrating the necessity of maintaining a PEG concentration of less than or equal to 800 ppm.

[0067] Similarly, as shown in Table 9, formulations C6 and C7, which both included greater than 800 ppm PEG in the resulting blown film, both cleared the melt fracture in less than 60 minutes, but caused surging during processing. Conversely, formulations I7-I8, which all had

resulting concentrations of PEG of less than or equal to 800 ppm, all cleared the melt fracture within 60 minutes, and also did not cause surging during processing.

[0068] Additionally, as can be seen in Table 10, when comparing C6 and C7 to I7 and I8, it is clear that although C6 and C7 had a slightly lower pressure fluctuation averages, C6 and C7 had much higher pressure fluctuation standard deviations than I7 and I8, which likely resulted in the surging that was observed.

[0069] The subject matter of the present disclosure has been described in detail and by reference to specific embodiments. It should be understood that any detailed description of a component or feature of an embodiment does not necessarily imply that the component or feature is essential to the particular embodiment or to any other embodiment. Further, it should be apparent to those skilled in the art that various modifications and variations can be made to the described embodiments without departing from the spirit and scope of the claimed subject matter.

[0070] It is noted that one or more of the following claims utilize the term “wherein” as a transitional phrase. For the purposes of defining the present technology, it is noted that this term is introduced in the claims as an open-ended transitional phrase that is used to introduce a recitation of a series of characteristics of the structure and should be interpreted in like manner as the more commonly used open-ended preamble term “comprising.”

[0071] It should be understood that where a first component is described as “comprising” a second component, it is contemplated that, in embodiments, the first component “consists” or “consists essentially of” that second component. It should further be understood that where a first component is described as “comprising” a second component, it is contemplated that, in embodiments, the first component comprises at least 10%, at least 20%, at least 30%, at least 40%, at least 50%, at least 60%, at least 70%, at least 80%, at least 90%, at least 95%, or even at least 99% that second component (where % can be weight % or molar %).

[0072] It is also noted that recitations herein of “at least one” component, element, etc., should not be used to create an inference that the alternative use of the articles “a” or “an” should be limited to a single component, element, etc.

CLAIMS

1. A method of reducing or eliminating melt fracture during extrusion comprising:
blending an ethylene-based polymer having a melt index (I_2) of less than 2.0 dg/min with a polymer processing aid (PPA) to remove the melt fracture during extrusion, wherein the PPA comprises:
non-functionalized polydimethylsiloxane (PDMS) having a kinematic viscosity range of 4,000 to 100,000 cSt; and
polyethylene glycol (PEG) having an average molecular weight (MW) of 1,000 to 10,000 g/mol, wherein the ratio by weight of PDMS to PEG is from 95:5 to 65:35.
2. The method of claim 1, wherein the ratio by weight of PDMS to PEG is from 90:10 to 70:30.
3. The method of claim 1 or 2, wherein the ethylene-based polymer has a melt index (I_2) from 0.05 to 1.5 dg/min.
4. The method of any one of claims 1 to 3, wherein the PPA is provided in a polymer masterbatch.
5. The method of claim 4, wherein the polymer masterbatch comprises from 1 to less than 15 wt. % PPA.
6. The method of any one of claims 1 to 5, wherein the method further comprises obtaining an extrusion product, wherein the extrusion product comprises 120 to 800 ppm PEG.
7. The method of any one of claims 1 to 6, wherein the method further comprises obtaining an extrusion product, wherein the extrusion product comprises at least 500 ppm of the PPA.
8. The method of any one of claims 1 to 7, wherein the melt fracture is removed within 60 minutes.
9. The method of any one of claims 1 to 8, wherein the PPA or a masterbatch thereof is dry blended or melt blended with the ethylene-based polymer.

10. The method of any one of claims 1 to 9, wherein the ethylene-based polymer comprises LLDPE.
11. An article produced from the method of any one of claims 1 to 10.
12. The use of a polymer processing aid (PPA) to remove melt fracture during extrusion, the use comprising blending ethylene-based polymer having a melt index (I_2) of less than 2.0 dg/min with the PPA, wherein the PPA comprises:
- non-functionalized polydimethylsiloxane (PDMS) having a kinematic viscosity range of 4000 to 100,000 cSt; and
 - polyethylene glycol (PEG) having an average molecular weight (MW) of 1,000 to 10,000 g/mol, wherein the ratio by weight of PDMS to PEG is from 95:5 to 65:35.
13. The use of a PPA of claim 12, wherein the PPA ratio by weight is from 90:10 to 70:30.
14. The use of a PPA of claim 12 or claim 13, wherein the ethylene-based polymer has a melt index (I_2) from 0.05 to 1.5 dg/min.
15. The use of a PPA of any one of claims 12 to 14, wherein the ethylene-based polymer comprises LLDPE.
16. A formulation comprising:
- an ethylene-based polymer having a melt index (I_2) of less than 2.0 dg/min;
 - a non-functionalized polydimethylsiloxane (PDMS) having a kinematic viscosity range of 4,000 to 100,000 cSt; and
 - polyethylene glycol (PEG) having an average molecular weight (MW) of 1,000 to 10,000 g/mol,
- wherein the ratio by weight of PDMS to PEG is from 95:5 to 65:35.
17. The formulation of claim 16, wherein the ratio by weight of PDMS to PEG is from 90:10 to 70:30.
18. The formulation of claim 16 or claim 17, wherein the ethylene-based polymer has a melt index (I_2) from 0.05 to 1.5 dg/min.

19. The formulation of any one of claims 16 to 18, wherein the formulation comprises 120 to 800 ppm PEG.

20. The formulation of any one of claims 16 to 19, wherein the ethylene-based polymer comprises LLDPE.