[0009] The combined strength and density reduction associated with foamed articles is not realized without a continuous polymer matrix throughout the part. Foamed parts having large polymer-free areas or voids compromise the structural integrity of the part, which makes such parts unfit for its intended use. These severe technical issues have limited the industrial application of polymer foams to many otherwise highly useful and beneficial applications. Accordingly, there is an ongoing need to provide improved methods for making foamed articles, particularly large or thick foamed articles. There is an ongoing need to obtain parts having a continuous foam structure throughout. There is a particular need to obtain parts having a thickness greater than 2 cm and having a continuous foam structure throughout. There is an ongoing need in the industry to address such needs using conventional apparatuses and materials.

SUMMARY OF THE INVENTION

[0009a] According to a first aspect of the present invention, there is provided a polymer foam article having a continuous thermoplastic polymer matrix defining a plurality of pneumatoceles throughout the entirety of the article, further wherein a surface region extending 500 microns from the surface of the article comprises compressed pneumatoceles throughout the entirety thereof.

[0009b] According to a second aspect of the present invention, there is provided a method of forming a polymer foam article, the method comprising:

heating and mixing a thermoplastic polymer with a pneumatogen source to form a molten pneumatic mixture, wherein the temperature of the molten pneumatic mixture exceeds the temperature at which the pneumatogen source produces a pneumatogen at atmospheric pressure, and wherein a pressure applied to the molten pneumatic mixture is sufficient to substantially prevent formation of pneumatoceles;

collecting a selected amount of the molten pneumatic mixture in a collection region;

defining an expansion volume in the collection region proximal to the molten pneumatic mixture to form a molten polymer foam from the molten pneumatic mixture;

dispensing the molten polymer foam from the collection region into a cavity defined by a mold, wherein the molten polymer foam contacts the surface of the mold defining the cavity; and

cooling the molten polymer foam in the mold cavity to form a solidified polymer foam article.

[0009c] According to a third aspect of the present invention, there is provided a polymer foam spheroid having a diameter of 3 inches [7.62 cm] to 6 inches [15.24 cm] and comprising a continuous thermoplastic polymer matrix defining a plurality of pneumatoceles throughout the entirety of the spheroid, wherein the thermoplastic polymer matrix has a density that is 35% to 85% less than the density of the thermoplastic polymer in the absence of the pneumatoceles.
[0009d] According to a fourth aspect of the present invention, there is provided a polymer foam cuboid having a minimum dimension of about 1 inch [2.54 cm] and comprising a continuous thermoplastic polymer matrix defining a plurality of pneumatoceles throughout the entirety of the cuboid, further wherein the thermoplastic polymer matrix has a density that is 35% to 85% less than the density of the thermoplastic polymer in the absence of the pneumatoceles.
[0009e] According to a fifth aspect of the present invention, there is provided a polymer foam spheroid having a diameter of 3 inches [7.62 cm] to 6 inches [15.24 cm] and comprising a continuous thermoplastic polymer matrix defining a plurality of pneumatoceles throughout the entirety of the spheroid, further wherein the thermoplastic polymer matrix excludes glass or polymer bubbles.
[0009f] According to a sixth aspect of the present invention, there is provided a polymer foam cuboid having a minimum dimension of about 1 inch [2.54 cm] and comprising a continuous thermoplastic polymer matrix defining a plurality of pneumatoceles throughout the entirety of the cuboid, further wherein the thermoplastic polymer matrix excludes glass or polymer bubbles.
[0009g] According to a seventh aspect of the present invention, there is provided a use of an injection molding machine to define a molten polymer foam and dispense the molten polymer foam into a cavity defined by a mold, wherein the dispensing causes the molten polymer foam to contact a surface of the mold cavity.
[0010] There is disclosed a method of making a molten polymer foam. The method includes: adding a thermoplastic polymer and a pneumatogen source to an extruder; heating and mixing the thermoplastic polymer and pneumatogen source in the extruder under a pressure to form a molten pneumatic mixture, wherein the temperature of the molten pneumatic mixture exceeds the critical temperature of the pneumatogen source; collecting an amount of the molten pneumatic mixture in a collection region of the extruder; defining an expansion volume in the collection region to cause a pressure to drop in the collection region; allowing an expansion period of time to elapse after the defining; and dispensing a molten polymer foam

from the collection region. In embodiments, the expansion volume is selected to provide between 10% and 300% of the total expected molten foam volume in the collection area. In embodiments, the expansion period is between 5 seconds and 600 seconds. In embodiments, the molten pneumatic mixture is undisturbed or substantially undisturbed during the expansion period.

[0011] In embodiments the dispensing is dispensing to a forming element; in some embodiments the forming element is a mold. In embodiments there is a fluid connection between the collection region of the extruder and the mold. In embodiments, the dispensing is an unimpeded flow of the molten polymer foam. In embodiments, the dispensing is a linear flow of molten polymer foam.

[0012] In embodiments the method further comprises cooling the dispensed molten polymer foam to a temperature below a melt transition of the thermoplastic polymer. In

embodiments, one or more additional materials to the extruder, wherein the one or more materials are selected from colorants, stabilizers, brighteners, nucleating agents, fibers, particulates, and fillers. In embodiments the pneumatogen source is a pneumatogen and the addition is a pressurized addition. In other embodiments the pneumatogen source comprises a bicarbonate, a polycarboxylic acid or a salt or ester thereof, or a mixture thereof.

[0013] There is disclosed a polymer foam article made in using the methods, materials, and apparatuses described herein. In embodiments, the polymer foam article has a foam structure throughout the entirety thereof characterized as a continuous polymer matrix defining a plurality of pneumatoceles therein. In embodiments, a surface region of a polymer foam article comprises compressed pneumatoceles. In embodiments, the surface region is the region extending 500 microns from the surface of the article.

[0014] There is disclosed thermoplastic polymer foam articles, the article having a foam structure throughout the entirety thereof that is a continuous polymer matrix defining a plurality of pneumatoceles therein, further wherein a surface region of the article comprises compressed pneumatoceles. In some embodiments, the surface region is the region of the article extending 500 microns from the surface thereof. In some embodiments, the article comprises compressed pneumatoceles more than 500 microns from the surface thereof. In embodiments, the polymer foam article comprises a thickness of more than 2 cm; in other embodiments the polymer foam article comprises a volume of more than 1000 cm^3, 1000 cm^3 to 5000 cm^3, or even more than 5000 cm^3; and in still other embodiments, the polymer foam article comprises a volume of more than 1000 cm^3 and a thickness of more than 2 cm, a volume between 1000 cm^3 and 5000 cm^3 and a thickness of more than 2 cm, or a volume of more than 5000 cm^3 and a thickness of more than 2 cm.

[0015] In embodiments, materials used to make the polymer foam articles are not particularly limited and include thermoplastic polymers selected from polyolefins, polyamides, polyimides, polyesters, polycarbonates, poly (lactic acid)s , acrylonitrile-butadiene-styrene copolymers, polystyrenes, polyurethanes, polyvinyl chlorides, copolymers of tetrafluoroethylene, polyethersulfones, polyacetals, polyaramids, polyphenylene oxides, polybutylenes, polybutadienes, polyacrylates and methacryates, ionomeric polymers, poly ether-amide block copolymers, polyaryletherkeytones, polysulfones, polyphenylene sulfides, polyamide-imide copolymers, poly(butylene

WHAT IS CLAIMED IS:

1. A polymer foam article having a continuous thermoplastic polymer matrix defining a plurality of pneumatoceles throughout the entirety of the article, further wherein a surface region extending 500 microns from the surface of the article comprises compressed pneumatoceles throughout the entirety thereof.

2. The polymer foam article of claim 1 wherein the article further comprises compressed pneumatoceles more than 500 microns from the surface thereof.

3. The polymer foam article of claim 1 or claim 2 wherein the thermoplastic polymer is selected from polyolefins, polyamides, polyimides, polyesters, polycarbonates, poly (lactic acid)s , acrylonitrile-butadiene-styrene copolymers, polystyrenes, polyurethanes, polyvinyl chlorides, copolymers of tetrafluoroethylene, polyethersulfones, polyacetals, polyaramids, polyphenylene oxides, polybutylenes, polybutadienes, polyacrylates and methacryates, ionomeric polymers, poly ether-amide block copolymers, polyaryletherkeytones, polysulfones, polyphenylene sulfides, polyamide-imide copolymers, poly(butylene succinate)s, cellulosics, or polysaccharides, or any copolymer, alloy, admixture, or blend thereof.

4. The polymer foam article of claim 1 or claim 2 wherein the continuous polymer matrix comprises a polyolefin, a polyamide, an ionically functionalized olefin copolymer, or a polyether-amide block copolymer.

5. The polymer foam article of any one of claims 1-4 wherein the continuous polymer matrix comprises a mixed plastic waste stream.

6. The polymer foam article of any one of claims 1-5 wherein the continuous polymer matrix further comprises one or more additional materials selected from colorants, stabilizers, brighteners, nucleating agents, fibers, particulates, and fillers.

7. The polymer foam article of any one of claims 1-5 wherein the continuous polymer matrix further comprises a talc or a colorant or both talc and a colorant.

8. The polymer foam article of any one of claims 1-7 wherein the polymer foam article comprises a thickness of more than 2 cm.

9. The polymer foam article of any one of claims 1-7 wherein the polymer foam article comprises a thickness of more than 5 cm.

10. The polymer foam article of any one of claims 1-7 wherein the polymer foam article comprises a thickness of more than 10 cm.

11. The polymer foam article of any one of claims 1-7 wherein the polymer foam article comprises a volume of more than 1000 cm^3.

12. The polymer foam article of any one of claims 1-7 wherein the polymer foam article comprises a volume of more than 5000 cm^3.

13. The polymer foam article of any one of claims 1-7 wherein the polymer foam article comprises a thickness of more than 2 cm and a volume of more than 1000 cm^3.

14. The polymer foam article of any one of claims 1-7 wherein the polymer foam article comprises a thickness of more than 5 cm and a volume of more than 1000 cm^3.

15. The polymer foam article of any one of claims 1-7 wherein the polymer foam article comprises a thickness of more than 5 cm and a volume of more than 5000 cm^3.

16. The polymer foam article of any one of claims 1-7 wherein the polymer foam article comprises a thickness of more than 10 cm and a volume of more than 5000 cm^3.

17. The polymer foam article of any one of claims 1-16 comprising a density reduction of 30% to 85%.

18. The polymer foam article of any one of claims 1-17 comprising a void fraction of 5% to 70%.

19. The polymer foam article of any one of claims 1-18 wherein the article is spheroid.

20. The polymer foam article of any one of claims 1-18 wherein the article is cuboid.

21. The polymer foam article of any one of claims 1-18 wherein the article comprises a dumbbell shape, a tableware shape, an ornamental globe shape having raised geographical features, a human shape, an animal shape, a frame or encasement shape, or a shape suitable for disposing screws, bolts, and the like into the article.

22. A method of forming a polymer foam article, the method comprising:

heating and mixing a thermoplastic polymer with a pneumatogen source to form a molten pneumatic mixture, wherein the temperature of the molten pneumatic mixture exceeds the temperature at which the pneumatogen source produces a pneumatogen at atmospheric pressure, and wherein a pressure applied to the molten pneumatic mixture is sufficient to substantially prevent formation of pneumatoceles;

collecting a selected amount of the molten pneumatic mixture in a collection region;

defining an expansion volume in the collection region proximal to the molten pneumatic mixture to form a molten polymer foam from the molten pneumatic mixture;

dispensing the molten polymer foam from the collection region into a cavity defined by a mold, wherein the molten polymer foam contacts the surface of the mold defining the cavity; and

cooling the molten polymer foam in the mold cavity to form a solidified polymer foam article.

23. The method of claim 22 wherein the dispensing comprises partially filling the mold cavity.

24. The method of claim 22 wherein the dispensing comprises substantially filling the mold cavity.

25. The method of claim 22 wherein the dispensing comprises completely filling the mold cavity.

26. The method of any one of claims 22-25 wherein the heating, mixing, collecting, defining, and dispensing are carried out using an injection molding machine.

27. The method of any one of claims 22-26 wherein the pneumatogen source is an organic compound.

28. The method of any one of claims 22-26 wherein the pneumatogen source is a pneumatogen.

29. The method of any one of claims 22-28 wherein the pneumatogen is CO_2 or N_2.

30. A polymer foam spheroid having a diameter of 3 inches [7.62 cm] to 6 inches [15.24 cm] and comprising a continuous thermoplastic polymer matrix defining a plurality of pneumatoceles throughout the entirety of the spheroid, wherein the thermoplastic polymer matrix has a density that is 35% to 85% less than the density of the thermoplastic polymer in the absence of the pneumatoceles.

31. The polymer foam spheroid of claim 30 wherein the thermoplastic polymer matrix has a density that is 50% to 85% less than the density of the thermoplastic polymer in the absence of the pneumatoceles.

32. The polymer foam spheroid of claim 30 or claim 31 wherein the thermoplastic polymer matrix comprises a mixed plastic waste stream.

33. A polymer foam cuboid having a minimum dimension of about 1 inch [2.54 cm] and comprising a continuous thermoplastic polymer matrix defining a plurality of pneumatoceles throughout the entirety of the cuboid, further wherein the thermoplastic polymer matrix has a density that is 35% to 85% less than the density of the thermoplastic polymer in the absence of the pneumatoceles.

34. The polymer foam cuboid of claim 33 wherein the thermoplastic polymer matrix has a density that is 50% to 85% less than the density of the thermoplastic polymer in the absence of the pneumatoceles.

35. The polymer foam cuboid of claim 33 or claim 34 wherein the thermoplastic polymer matrix comprises a mixed plastic waste stream.

36. The polymer foam cuboid of any one of claims 33-35 having dimensions of about 1 inch [2.54 cm] by 1 inch [2.54 cm] by 2 inches [5.08 cm], or about 1 inch [2.54 cm] by 4 inches [10.16 cm] by 11 inches [27.94 cm], or about 1 inch [2.54 cm] by 4 inches[10.16 cm] by 17 inches [43.18 cm] or about 1 inch [2.54 cm] by 12 inches [30.48 cm] by 12 inches [30.48 cm] or about 2 inches [5.08 cm] by 2 inches [5.08 cm] by 2 inches [5.08 cm], or about 2 inches [5.08 cm] by 4 inches [10.16 cm] by 11 inches [27.94 cm] or about 2 inches [5.08 cm] by 4 inches [10.16 cm] by 4 inches [10.16 cm], or about 4 inches [10.16 cm] by 4 inches [10.16 cm] by 4 inches [10.16 cm] or about 12 inches [30.48 cm] by 12 inches [30.48 cm] by 12 inches [30.48 cm].

37. A polymer foam spheroid having a diameter of 3 inches [7.62 cm] to 6 inches [15.24 cm] and comprising a continuous thermoplastic polymer matrix defining a plurality of pneumatoceles throughout the entirety of the spheroid, further wherein the thermoplastic polymer matrix excludes glass or polymer bubbles.

38. The polymer foam spheroid of claim 37 wherein the thermoplastic polymer matrix has a density that is 30% to 85% less than the density of the thermoplastic polymer in the absence of the pneumatoceles.

39. The polymer foam spheroid of claim 37 or 38 wherein spheroid comprises a void fraction of 5% to 70%.

40. The polymer foam spheroid of any one of claims 37-39 wherein the thermoplastic polymer matrix comprises a mixed plastic waste stream.

41. A polymer foam cuboid having a minimum dimension of about 1 inch [2.54 cm] and comprising a continuous thermoplastic polymer matrix defining a plurality of pneumatoceles throughout the entirety of the cuboid, further wherein the thermoplastic polymer matrix excludes glass or polymer bubbles.

42. The polymer foam cuboid of claim 41 wherein the thermoplastic polymer matrix has a density that is 30% to 85% less than the density of the thermoplastic polymer in the absence of the pneumatoceles.

43. The polymer foam cuboid of claim 41 or claim 42 wherein cuboid comprises a void fraction of 5% to 70%.

44. The polymer foam cuboid of any one of claims 42-43 having dimensions of about 1 inch [2.54 cm] by 1 inch [2.54 cm] by 2 inches [5.08 cm], or about 1 inch [2.54 cm] by 4 inches [10.16 cm] by 11 inches [27.94 cm], or about 1 inch [2.54 cm] by 4 inches[10.16 cm] by 17 inches [43.18 cm] or about 1 inch [2.54 cm] by 12 inches [30.48 cm] by 12 inches [30.48 cm] or about 2 inches [5.08 cm] by 2 inches [5.08 cm] by 2 inches [5.08 cm], or about 2 inches [5.08 cm] by 4 inches [10.16 cm] by 11 inches [27.94 cm] or about 2 inches [5.08 cm] by 4 inches [10.16 cm] by 4 inches [10.16 cm], or about 4 inches [10.16 cm] by 4 inches [10.16 cm] by 4 inches [10.16 cm] or about 12 inches [30.48 cm] by 12 inches [30.48 cm] by 12 inches [30.48 cm].

45. The polymer foam cuboid of any one of claims 41-44 wherein the thermoplastic polymer matrix comprises a mixed plastic waste stream.

46. Use of an injection molding machine to define a molten polymer foam and dispense the molten polymer foam into a cavity defined by a mold, wherein the dispensing causes the molten polymer foam to contact a surface of the mold cavity.