CLAIMS

What is claimed is:

1. A method of improving processing of polyethylene resins comprising:

obtaining a plurality of multimodal metallocene-catalyzed polyethylene samples;

measuring the shear stress as a function of shear rate for the plurality of multimodal metallocene-catalyzed polyethylene samples using capillary rheometry wherein the measuring yields values for a magnitude of slip-stick, a stress for smooth to matte transition, and a shear rate for smooth to matte transition; and

identifying from the plurality of multimodal metallocene-catalyzed polyethylene samples individual multimodal metallocene-catalyzed polyethylene resins having a reduced tendency to melt fracture characterized by a magnitude of slip-stick greater than about 300 psi, a stress for smooth to matte transition greater than about 90 kPa, and a shear rate for smooth to matte transition greater than about 10 s^{-1}.

2. The method of claim 1 wherein each of the plurality of multimodal metallocene-catalyzed polyethylene samples comprises a polymer blend.

3. The method of any of claims 1 to 2 wherein each of the plurality of multimodal metallocene-catalyzed polyethylene samples comprises a higher molecular weight component and a lower molecular weight component.

4. The method of claim 3 wherein the higher molecular weight component has a peak molecular weight ranging from about 67 kg/mol to about 600 kg/mol and the lower molecular weight component has a peak molecular weight ranging from about 25 kg/mol to about 65 kg/mol.

5. The method of any of claims 1 to 4 wherein each of the plurality of multimodal metallocene-catalyzed polyethylene samples has a molecular weight distribution of from about 5 to about 30.

6. The method of any of claims 1 to 5 wherein each of the plurality of multimodal metallocene-catalyzed polyethylene samples has a magnitude of stick-slip of from greater than about 300 psi to about 1500 psi.

7. The method of any of claims 1 to 6 wherein each of the plurality of multimodal metallocene-catalyzed polyethylene samples has a shear rate for smooth to matte transition of from greater than about 10 s^{-1} to about 100 s^{-1}.

8. The method of any of claims 1 to 7 wherein the melt fracture is sharkskin melt fracture, slip-stick fracture or gross melt fracture.

9. A method of improving processing of polyethylene resins comprising:

obtaining a known molecular weight distribution, a known magnitude of slip-stick, a known stress for smooth to matte transition, and a known shear rate for smooth to matte transition, for each of a plurality of polyethylene resins;

performing chemometric analysis to determine an analytical relationship between the known molecular weight distribution, the known magnitude of slip-stick, the known stress for smooth to matte transition, and the known shear rate for smooth to matte transition for the plurality of polyethylene resins;

obtaining a plurality of multimodal metallocene-catalyzed polyethylene resins, each having a known molecular weight distribution, an unknown magnitude of slip-stick, an unknown stress for smooth to matte transition, and an unknown shear rate for smooth to matte transition;

utilizing the analytical relationship to determine a value for the unknown magnitude of slip-stick, a value for the unknown stress for smooth to matte transition, and the unknown shear rate for smooth to matte transition for each of the plurality of multimodal metallocene-catalyzed polyethylene samples; and

identifying from the plurality of multimodal metallocene-catalyzed polyethylene resins individual multimodal metallocene-catalyzed polyethylene resins having a reduced tendency to melt fracture characterized by a magnitude of slip-stick greater than about 300 psi, a stress for smooth to matte transition greater than about 90 kPa, and a shear rate for smooth to matte transition greater than about 10 s^{-1}.

10. The method of claim 9 wherein the analytical relationship is a mathematical equation.

11. The method of any of claims 9 to 10 wherein the analytical relationship is established using at least one chemometric technique selected from the group consisting of Partial Least Squares Regression (PLS), Multilinear Regression Analysis (MLR), Principal Components Regression (PCR), Principal Component Analysis (PCA) and Discriminant Analysis, Design of Experiment (DOE) and Response Surface Methodologies.

12. The method of any of claims 9 to 11 wherein the plurality of polyethylene resins comprises equal to or greater than about 10 samples.

13. The method of any of claims 9 to 12 wherein the known molecular weight distribution is from about 5 to about 30.

14. The method of any of claims 9 to 13 wherein the known magnitude of slip-stick is from about 300 psi to about 1500 psi.

15. The method of any of claims 9 to 14 wherein the known stress for smooth to matte transition is less than about 200 kPa.

16. The method of any of claims 9 to 15 wherein the known shear rate for smooth to matte transition is from greater than about 10 s^{-1} to about 100 s^{-1}.

17. The method of any of claims 9 to 16 wherein the individual multimodal metallocene-catalyzed polyethylene resins having a reduced tendency to melt fracture comprise a higher molecular weight component and a lower molecular weight component.

18. The method of claim 17 wherein the higher molecular weight component has a peak molecular weight ranging from about 67 kg/mol to about 600 kg/mol and the lower molecular weight component has a peak molecular weight ranging from about 25 kg/mol to about 65 kg/mol.

19. The method of any of claims 9 to 18 wherein the individual multimodal metallocene-catalyzed polyethylene resins having a reduced tendency to melt fracture comprise a comonomer.

20. The method of any of claims 9 and 19 further comprising identifying individual multimodal metallocene-catalyzed polyethylene resins having an increased tendency to melt fracture.

21. The method of any of claims 1 to 8 further comprising forming one or more of the individual multimodal metallocene-catalyzed polyethylene resins having a reduced tendency to melt fracture into an article.

22. The method of any of claims 9 to 20 further comprising forming one or more of the individual multimodal metallocene-catalyzed polyethylene resins having a reduced tendency to melt fracture into an article.

23. The method of any of claims 1 to 8 further comprising providing one or more of the individual multimodal metallocene-catalyzed polyethylene resins having a reduced tendency to melt fracture to a user in need thereof.

24. The method of any of claims 9 to 20 further comprising providing one or more of the individual multimodal metallocene-catalyzed polyethylene resins having a reduced tendency to melt fracture to a user in need thereof.

25. A system for improving processing of polyethylene resins, comprising:

a processor;

a memory;

an output device; and

an analysis component stored in the memory, that when executed on the processor, configures the processor to:

receive a shear stress as a function of shear rate for a plurality of multimodal metallocene-catalyzed polyethylene samples, wherein the determination of the shear stress as a function of the shear rate comprises using capillary rheometry;

determine values for a magnitude of slip-stick, a stress for smooth to matte transition, and a shear rate for smooth to matte transition for each of the plurality of multimodal metallocene-catalyzed polyethylene samples based on the shear stress and the shear rate measured from capillary rheometry;

identify individual multimodal metallocene-catalyzed polyethylene resins from the plurality of multimodal metallocene-catalyzed polyethylene samples having a reduced tendency to melt fracture characterized by a magnitude of slip-stick greater than about 300 psi, a stress for smooth to matte transition greater than about 90 kPa, and a shear rate for smooth to matte transition greater than about 10 s^{-1}; and

output an identification of the individual multimodal metallocene-catalyzed polyethylene resins to the output device.

26. The system of claim 25 wherein each of the plurality of multimodal metallocene-catalyzed polyethylene samples comprises a polymer blend.

27. The system of any of claims 25 to 26 wherein each of the plurality of multimodal metallocene-catalyzed polyethylene samples comprises a higher molecular weight component and a lower molecular weight component, and wherein the values for the slip-stick, the stress for smooth to matte transition, and the shear rate for smooth to matte transition are further determined based on at least one property of the higher molecular weight component and at least one property of the lower molecular weight components.

28. The system of any of claims 25 to 27 wherein each of the plurality of multimodal metallocene-catalyzed polyethylene samples has a shear rate for smooth to matte transition of from greater than about 10 s^{-1} to about 100 s^{-1}.

29. A system for improving processing of polyethylene resins comprising:

a processor;

a memory;

an output device; and

an analysis component stored in the memory, that when executed on the processor, configures the processor to:

receive a known molecular weight distribution, a known magnitude of slip-stick, a known stress for smooth to matte transition, and a known shear rate for smooth to matte transition for each of a plurality of polyethylene resins;

determine, using chemometric analysis, an analytical relationship between the known molecular weight distribution, the known magnitude of slip-stick, the known stress for smooth to matte transition, and the known shear rate for smooth to matte transition for the plurality of polyethylene resins;

receiving a known molecular weight distribution for each of a plurality of multimodal metallocene-catalyzed polyethylene samples;

determine, using the analytical relationship, a value for an unknown magnitude of slip-stick, a value for an unknown stress for smooth to matte transition, and a value for an unknown shear rate for smooth to matte transition for each of the plurality of multimodal metallocene-catalyzed polyethylene samples based on the known molecular weight distribution for each of the plurality of multimodal metallocene-catalyzed polyethylene samples; and

identify individual multimodal metallocene-catalyzed polyethylene samples from the plurality of multimodal metallocene-catalyzed polyethylene samples having a

reduced tendency to melt fracture, wherein individual multimodal metallocene-catalyzed polyethylene samples have a reduced tendency to melt fracture when a value of slip-stick is greater than about 300 psi, a stress for smooth to matte transition is greater than about 90 kPa of stress, and a shear rate for smooth to matte transition is greater than about 10 $s^{-1;}$

output an identification of the individual multimodal metallocene-catalyzed polyethylene samples to the output device.

30. The system of claim 29 wherein the analytical relationship is a mathematical equation.

31. The system of any of claims 29 to 30 wherein the analytical relationship is determined using at least one chemometric technique selected from the group consisting of; Partial Least Squares Regression (PLS), Multilinear Regression Analysis (MLR), Principal Components Regression (PCR), Principal Component Analysis (PCA) and Discriminant Analysis, Design of Experiment (DOE), and Response Surface Methodologies.

32. The system of any of claims 29 to 31 wherein the plurality of polyethylene resins comprises equal to or greater than about 10 samples.

33. The system of any of claims 29 to 32 wherein the known molecular weight distribution is from about 5 to about 30.

34. The system of any of claims 29 to 33 wherein the known magnitude of slip-stick is from about 300 psi to about 1500 psi.

35. The system of any of claims 29 to 34 wherein the known stress for a smooth to matte transition is less than about 200 kPa.

36. The system of any of claims 29 to 35 wherein the known shear rate for a smooth to matte transition is from greater than about 10 s^{-1} to about 100 s^{-1}.

37. The system of any of claims 29 to 36 wherein the individual multimodal metallocene-catalyzed polyethylene samples having a reduced tendency to melt fracture comprise a higher molecular weight component and a lower molecular weight component.

38. The system of any of claims 29 to 37 wherein the analysis component further configures the processor identify individual multimodal metallocene-catalyzed polyethylene samples having an increased tendency to melt fracture.

39. A computer implemented method for improving processing of polyethylene resins, comprising:

receiving by a processor, a shear stress as a function of shear rate for a plurality of multimodal metallocene-catalyzed polyethylene samples, wherein the determination of the shear stress as a function of the shear rate comprises using capillary rheometry;

determining, by the processor, values for a slip-stick, a stress for smooth to matte transition, and a shear rate for smooth to matte transition for each of the plurality of multimodal metallocene-catalyzed polyethylene samples based on the shear stress and the shear rate;

identifying, by the processor, individual multimodal metallocene-catalyzed polyethylene resins from the plurality of multimodal metallocene-catalyzed polyethylene samples having a reduced tendency to melt fracture characterized by a magnitude of slip-stick greater than about 300 psi, a stress for smooth to matte transition greater than about 90 kPa of stress, and a shear rate for smooth to matte transition greater than about 10 s^{-1}; and

outputting, by the processor, an identification of the individual multimodal metallocene-catalyzed polyethylene resins to an output device.

40. A computer implemented method for improving processing of polyethylene resins comprising:

an analysis component stored in the memory, that when executed on the processor, configures the processor to:

receiving, by an analysis component stored in a memory and executed on a processor, a known molecular weight distribution, a known magnitude of slip-stick, a known stress for smooth to matte transition, and a known shear rate for each of a plurality of polyethylene resins;

determining, by the analysis component, an analytical relationship between the known molecular weight distribution, the known magnitude of slip-stick, the known stress for smooth to matte transition, and the known shear rate for smooth to matte transition for the plurality of polyethylene resins using chemometric analysis;

receiving a known molecular weight distribution for each of a plurality of multimodal metallocene-catalyzed polyethylene samples;

determining, by the analysis component, a value for an unknown magnitude of slip-stick, a value for an unknown stress for smooth to matte transition, and a value for an unknown shear rate for smooth to matte transition for each of the plurality of multimodal metallocene-catalyzed polyethylene samples using the analytical relationship, wherein the determining of the value for an unknown magnitude of slip-stick, the value for an unknown stress for smooth to matte transition, and the value for the unknown shear rate for a smooth to matte transition is based on the

known molecular weight distribution for each of the plurality of multimodal metallocene-catalyzed polyethylene samples; and

identifying, by the analysis component, individual multimodal metallocene-catalyzed polyethylene samples from the plurality of multimodal metallocene-catalyzed polyethylene samples having a reduced tendency to melt fracture, wherein individual multimodal metallocene-catalyzed polyethylene samples have a reduced tendency to melt fracture when a value of magnitude of slip-stick is greater than about 300 psi, a stress for smooth to matte transition is greater than about 90 kPa, and a shear rate for smooth to matte transition is greater than about 10 s^{-1};

output, by the analysis component, an identification of the individual multimodal metallocene-catalyzed polyethylene samples to the output device.

41. The method of claim 40, wherein the analytical relationship is a mathematical equation.

42. The method of any of claims 40 to 41 wherein the analytical relationship is determined using at least one chemometric technique selected from the group consisting of; Partial Least Squares Regression (PLS), Multilinear Regression Analysis (MLR), Principal Components Regression (PCR), Principal Component Analysis (PCA) and Discriminant Analysis, Design of Experiment (DOE), and Response Surface Methodologies.

43. The method of any of claims 40 to 42 wherein the plurality of polyethylene resins comprises equal to or greater than about 10 samples.

44. The method of any of claims 40 to 43 further comprising identifying, by the analysis component, individual multimodal metallocene-catalyzed polyethylene samples having an increased tendency to melt fracture.

45. A method of preparing a medium-density polyethylene pipe comprising:

melting a multimodal metallocene-catalyzed polyethylene resin to form a molten polyethylene, wherein the multimodal metallocene-catalyzed polyethylene resin has a density of from about 0.925 g/ml to about 0.942 g/ml, a magnitude of slip-stick greater than about 300 psi, a stress for smooth to matte transition of greater than about 90 kPa of stress, and a shear rate for smooth to matte transition greater than about 10 s^{-1}, wherein the magnitude of slip-stick, stress for smooth to matte transition, and shear rate for smooth to matte transition are determined by a capillary rheology test; and

forming the molten polyethylene resin into pipe.

46. The method of claim 45 wherein the polyethylene resin has a density of from about 0.928 g/ml to about 0.940 g/ml.

47. The method of any of claims 45 to 46 wherein the polyethylene resin has a melt flow rate of less than about 0.4 g/10 min.

48. The method of any of claims 45 to 47 wherein the pipe has a PENT value of from about 500 hours to about 20,000 hours.

49. The method of any of claims 45 to 48 wherein the pipe has a Charpy T_{db} of less than about –25°C.

50. The method of any of claims 45 to 49 wherein the pipe has a Charpy impact energy of from about 1.0 J to about 3.0 J.

51. The method of any of claims 45 to 50 wherein the pipe has a flexural modulus, 2% secant of from about 80 kpsi to about 110 kpsi.

52. The method of any of claims 45 to 51 wherein the pipe has an elongation at break of greater than about 450%.

53. The method of any of claims 45 to 52 wherein the pipe has a Young's modulus of from about 120 kpsi to about 190 kpsi.

54. The method of any of claims 45 to 53 wherein the pipe has a tensile strength at yield of from about 2600 psi to less than about 3,000 psi.

55. The method of any of claims 45 to 54 wherein the pipe has a tensile strength at break of greater than about 3000 psi.

56. The method of any of claims 45 to 55 wherein the pipe has a thermal stability of greater than about 220°C.

57. The method of any of claims 45 to 56 wherein the pipe has a critical temperature value (T_c) of equal to or less than about 0°C.

58. The method of any of claims 45 to 57 wherein the pipe has a critical pressure value (P_c) of greater than about 12 bar.

59. The method of any of claims 45 to 58 wherein the pipe has a tensile natural draw ratio of less than about 500%.

60. The method of any of claims 45 to 59 wherein the pipe has a hydrostatic design basis at 23°C of from about 1200 psi to less than about 1530 psi and at 60°C of from about 960 psi to less than about 1200 psi.

61. The method of any of claims 45 to 60 wherein the pipe has a minimum required strength of from about $8 \leq \sigma LPL < 10$ MPa.

62. A pipe prepared from a multimodal metallocene-catalyzed polyethylene resin having a density of from about 0.925 g/ml to about 0.942 g/ml, a magnitude of slip-stick greater than about 300 psi, a stress for smooth to matte transition of greater than about 90 kPa, and a shear rate for smooth to matte transition greater than about 10 s^{-1}, wherein the magnitude of slip-stick, stress for smooth to matte transition, and shear rate for smooth to matte transition are determined by a capillary rheology test.

63. The pipe of claim 62 having a PENT value of from about 500 hours to about 20,000 hours.

64. The pipe of any of claims 62 to 63 having a Charpy T_{db} of less than about –25°C.

The invention claimed is:

1. A method of preparing a medium-density polyethylene pipe comprising: melting a multimodal metallocene-catalyzed polyethylene resin to form a molten polyethylene, wherein the multimodal metallocene-catalyzed polyethylene resin has a density of from about 0.925 g/ml to about 0.942 g/ml, a magnitude of slip-stick greater than about 300 psi, a stress for smooth to matte transition of greater than about 90 kPa of stress, and a shear rate for smooth to matte transition greater than about 10 s^{-1}, wherein the magnitude of slip-stick, stress for smooth to matte transition, and shear rate for smooth to matte transition are determined by a capillary rheology test; and forming the molten polyethylene resin into pipe.

2. The method of claim 1 wherein the polyethylene resin has a density of from about 0.928 g/ml to about 0.940 g/ml.

3. The method of claim 1 wherein the polyethylene resin has a melt flow rate of less than about 0.4 g/10 min.

4. The method of claim 1 wherein the pipe has a PENT value of from about 500 hours to about 20,000 hours.

5. The method of claim 1 wherein the pipe has a Charpy T_{db} of less than about −25° C.

6. The method of claim 1 wherein the pipe has a Charpy impact energy of from about 1.0 J to about 3.0 J.

7. The method of claim 1 wherein the pipe has a flexural modulus, 2% secant of from about 80 kpsi to about 110 kpsi.

8. The method of claim 1 wherein the pipe has an elongation at break of greater than about 450%.

9. The method of claim 1 wherein the pipe has a Young's modulus of from about 120 kpsi to about 190 kpsi.

10. The method of claim 1 wherein the pipe has a tensile strength at yield of from about 2600 psi to less than about 3,000 psi.

11. The method of claim 1 wherein the pipe has a tensile strength at break of greater than about 3000 psi.

12. The method of claim 1 wherein the pipe has a thermal stability of greater than about 220° C.

13. The method of claim 1 wherein the pipe has a critical temperature value (T_c) of equal to or less than about 0° C.

14. The method of claim 1 wherein the pipe has a critical pressure value (P_c) of greater than about 12 bar.

15. The method of claim 1 wherein the pipe has a tensile natural draw ratio of less than about 500%.

16. The method of claim 1 wherein the pipe has a hydrostatic design basis at 23° C. of from about 1200 psi to less than about 1530 psi and at 60° C. of from about 960 psi to less than about 1200 psi.

17. The method of claim 1 wherein the pipe has a minimum required strength of from about $8 \leqq \sigma LPL < 10$ MPa.

18. A pipe prepared from a multimodal metallocene-catalyzed polyethylene resin having a density of from about 0.925 g/ml to about 0.942 g/ml, a magnitude of slip-stick greater than about 300 psi; a stress for smooth to matte transition of greater than about 90 kPa, and a shear rate for smooth to matte transition greater than about 10 s^{-1}, wherein the magnitude of slip-stick, stress for smooth to matte transition, and

shear rate for smooth to matte transition are determined by a capillary rheology test.

19. The pipe of claim 18 having a PENT value of from about 500 hours to about 20,000 hours.

20. The pipe of claim 18 having a Charpy T_{db} of less than about −25° C.