

A PROPYLENE-BASED COPOLYMER AND METHODS FOR MAKING THE SAME

FIELD

5 [0001] This application claims the benefit of U.S. Provisional Patent Application 63/600,174 filed 17 November 2023 entitled "POLYMER RESIN USING ETHYLENE MONOMERS FOR MORE EFFICIENT FOAMING PROCESSES," the entirety of which is incorporated by reference herein.

10 [0002] This disclosure relates to a composition of matter, and techniques for producing the composition of matter, that includes random copolymers (RCPs) or resins using a mixture including propylene monomers and ethylene monomers. In particular, the techniques may include using a mixture having an ethylene monomer content that is between approximately 2% and approximately 7% by weight. The composition of matter and processes of this disclosure are especially useful for foaming processes.

15 BACKGROUND

[0003] Certain industrial systems may produce a variety of polymer mixtures, such as copolymers and copolymer mixtures, during operation of the industrial systems. In certain instances, the copolymers may be used in applications such as compounding, film sealants, photovoltaic encapsulation films, foaming and general polymer modification. Certain functional
20 attributes (e.g., mechanical properties, strength, toughness, and compatibilization) are considered important, and thus it would be beneficial for composition methods and processes to address obtaining these considerations in a single copolymer.

[0004] Propylene is increasingly used as a base material in processes (e.g., propylene-based thermoplastic elastomers (TPE)). Additionally, polypropylene may be utilized to form a foamable
25 polymer. Particularly, polypropylene random copolymers (e.g., resins) with high stiffness may be useful for the production of expanded bead foams (EPPs). In certain conventional compositions and techniques, EPPs are made using polypropylene random copolymers having a relatively low ethylene content (e.g., C₂ amount % or C₂%) of about 3% with a flexural modulus of about 650MPa to about 750MPa and melting temperature (T_m) of about 147°C. In order to expand use
30 of polypropylene random copolymers to applications requiring higher stiffness, where instead injection molded parts are currently being used, it may be desirable to utilize higher stiffness grade resins (e.g. having a flexural modulus >700 MPa) while maintaining a resin melting temperature

below about 154°C. In general, these conditions correspond to a steam pressure threshold of approximately 5 Bar steam pressure for certain steam chests where pre-expanded beads coming out of an autoclave are then molded into three-dimensional foam parts.

SUMMARY

5 **[0005]** A summary of certain embodiments disclosed herein is set forth below. It should be understood that these aspects are presented merely to provide the reader with a brief summary of these certain embodiments and that these aspects are not intended to limit the scope of this disclosure. Indeed, this disclosure may encompass a variety of aspects that may not be set forth below.

10 **[0006]** In one embodiment, the present disclosure relates to a propylene-based copolymer produced from a mixture of ethylene monomers and propylene monomers. The propylene-based copolymer includes a flexural modulus between approximately 400 MPa and approximately 1100 MPa and a molecular weight of about 200,000 g/mol to 800,000 g/mol. A r_1r_2 reactivity ratio of the propylene-based copolymer is greater than or equal to 2.0, and the propylene-based copolymer
15 includes an ethylene content greater than approximately 2.5 weight percent (wt.%).

[0007] In another embodiment, the present disclosure relates to a method. The method includes providing an ethylene feedstock at a first flow rate. The method also includes providing a propylene feedstock at a second flow rate. A ratio (C2/C3) of the first flow rate to the second flow rate is less than or equal to approximately 0.06. Further, the method includes generating an
20 ethylene-propylene composition by contacting the propylene feedstock and the ethylene feedstock in the presence of a catalyst.

[0008] In another embodiment, the present disclosure relates to a method. The method includes providing an ethylene feedstock at a first flow rate. The method also includes providing a propylene feedstock at a second flow rate. The ratio ([C2]/[M]) of an amount of ethylene
25 monomer and a sum of an amount of ethylene monomers and propylene monomers in a reactor is between less than or equal to approximately 0.025. Further, the method includes generating an ethylene-propylene composition by contacting the propylene feedstock and the ethylene feedstock in the presence of a catalyst.

[0009] These and other features and attributes of the present disclosure and their advantageous
30 applications and/or uses will be apparent from the detailed description which follows.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] To assist those of ordinary skill in the relevant art in making and using the subject matter hereof, reference is made to the appended drawings, wherein:

[0011] FIG. 1 is a flow diagram of a method for producing a random copolymer (RCP) and/or a resin based on ethylene and propylene, in accordance with the present disclosure;

[0012] FIG. 2 is a graph illustrating flexural modulus versus melt temperature of different polymers and RCPs including RCPs made in accordance with the method of FIG. 1, in accordance with the present disclosure;

[0013] FIG. 3 is a graph illustrating crystallization rates versus temperature of RCPs made with varying C2 amounts in accordance with the method of FIG. 1, in accordance with the present disclosure;

[0014] FIG. 4 is a graph illustrating expansion ratio versus temperature of a resin made in accordance with the method of FIG. 1, in accordance with the present disclosure;

[0015] FIG. 5 is a graph illustrating log of flexural modulus 1% secant versus C2 content of a resin made in accordance with the method of FIG. 1, in accordance with the present disclosure;

[0016] FIG. 6 is a graph illustrating log of flexural modulus 1% secant versus C2 content of a resin made in accordance with the method of FIG. 1, in accordance with the present disclosure;

[0017] FIG. 7 is a graph illustrating measured log of flexural modulus 1% secant vs. predicted log of flexural modulus 1% secant of a resin made in accordance with the method of FIG. 1, in accordance with the present disclosure;

[0018] FIG. 8 is a graph illustrating size properties of a copolymer composition made using the techniques of FIG. 1, in accordance with the present disclosure; and

[0019] FIG. 9 is a graph illustrating size properties of a copolymer composition made using the techniques of FIG. 1, in accordance with the present disclosure.

DETAILED DESCRIPTION

[0020] One or more specific embodiments of the present disclosure will be described below. In an effort to provide a concise description of these embodiments, all features of an actual

implementation may not be described in the specification. It should be appreciated that in the development of any such actual implementation, as in any engineering or design project, numerous implementation-specific decisions must be made to achieve the developers' specific goals, such as compliance with system-related and business-related constraints, which may vary from one implementation to another. Moreover, it should be appreciated that such a development effort might be complex and time consuming, but would nevertheless be a routine undertaking of design, fabrication, and manufacture for those of ordinary skill having the benefit of this disclosure.

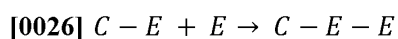
[0021] When introducing elements of various embodiments of the present disclosure, the articles "a," "an," "the," and "said" are intended to mean that there are one or more of the elements. The terms "comprising," "including," and "having" are intended to be inclusive and mean that there may be additional elements other than the listed elements. All numerical values within the detailed description herein are modified by "about" the indicated value, and take into account experimental error and variations that would be expected by a person having ordinary skill in the art. For example, "about" or "approximately" may refer to $\pm 0.5\%$, $\pm 1\%$, ± 2 , $\pm 5\%$, $\pm 10\%$, or $\pm 15\%$.

[0022] For purposes herein a "polymer" has two or more of the same or different monomer ("mer") units. A "homopolymer" is a polymer having mer units that are the same. A "copolymer" is a polymer having two or more mer units that are different from each other. A "terpolymer" is a polymer having three mer units that are different from each other. "Different" in reference to mer units indicates that the mer units differ from each other by at least one atom or are different isomerically. Accordingly, copolymer, as used herein, can include terpolymers and the like. An oligomer is typically a polymer having a low molecular weight, such as M_n of less than 25,000 g/mol, or less than 2,500 g/mol, or a low number of mer units, such as 75 mer units or less or 50 mer units or less. As used herein, the term C2 refers to ethylene, C3 refers to propylene. An "ethylene polymer" or "ethylene copolymer" is a polymer or copolymer comprising at least 50 mol % ethylene derived units, a "propylene polymer" or "propylene copolymer" is a polymer or copolymer comprising at least 50 mol % propylene derived units, and so on. " M_w " refers to the weight average molecular weight of the different polymers in a polymeric material. " M_n " refers to the number average molecular weight of the different polymers in a polymeric material. " M_z " refers to the z average molecular weight of the different polymers in a polymeric material. The terms "molecular weight distribution" (MWD) and "polydispersity index" (PDI) are used interchangeably to refer to the ratio of M_w to M_n . Unless otherwise noted, all molecular weights (e.g., M_w , M_n , M_z) are reported in units of g/mol.

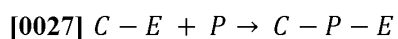
[0023] As used herein, the term “mole fraction” (mol fraction) refers to a fraction of moles of a polymer unit in a resin. The term mole percent (mol %) refers to a percentage of moles of a defect within a resin. As used herein, the term meso-meso (%mm) describes the stereochemistry of pairs of contiguous propylene groups, “m” referring to meso. The term “mm triad tacticity index” of a polymer is a measure of the relative isotacticity of a sequence of three adjacent propylene units connected in a head-to-tail configuration. In the present disclosure, the mm triad tacticity index of a polypropylene homopolymer or copolymer is expressed as 100 times the mm fraction; this product equals the %mm.

[0024] Furthermore, suitable propylene-based copolymers may have a comonomer distribution that is uniform, orthogonal, or conventional. A uniform comonomer distribution means that the comonomer content is constant along the length of a polymer chain. Uniform comonomer distributions are associated with metallocene catalysts, which typically produce propylene-based elastomers that have a narrow molecular weight distribution and a uniform distribution of comonomer along the length of the polymer chain. A conventional comonomer distribution is where the comonomer composition varies along the length of a polymer chain (also known as a “broad comonomer distribution” or “non-uniform comonomer distribution”). The term “broad orthogonal comonomer distribution” (BOCD) refers to a positively sloped comonomer content profile along the log Mw of a polymer.

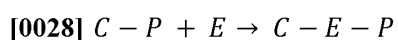
[0025] As used herein, the term “reactivity ratio” (r_1r_2) is representative of blockiness index. A blocky copolymer exhibits a reactivity ratio (r_1r_2) greater than 1, wherein r_1 accounts for ethylene and r_2 accounts for propylene, respectively. A copolymerization between monomers “E” and “P” in the presence of catalyst “C” can be represented by the following reaction schemes and rate equations where R_{11} is the rate of “E” insertion after “E”, R_{12} is the rate of “P” insertion after “E”, R_{21} is the rate of “E” insertion after “P”, R_{22} is the rate of “P” insertion after “P”, and k_{11} , k_{12} , k_{21} , k_{22} are the corresponding rate constants for each. The reactions scheme and rate equations are illustrated below.



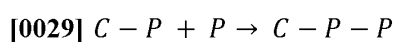
$$R_{11} = k_{11}[C - E][E]$$



$$R_{12} = k_{12}[C - E][P]$$



$$R_{21} = k_{21}[C - P][E]$$



$$R_{22} = k_{22}[C - P][P]$$

[0030] The reactivity ratios r_1 and r_2 are:

$$[0031] \quad r_1 = \frac{k_{11}}{k_{12}} \quad r_1 = \frac{k_{22}}{k_{21}}$$

$$\text{[0032]} \quad r_1 r_2 = \frac{k_{11} k_{22}}{k_{12} k_{21}}$$

[0033] The product of r_1 and r_2 provides information on how the different monomers distribute themselves along the polymer chain. Below, are illustrations of alternating, random, and blocky copolymers and how the product of $r_1 \times r_2$ relates to each:

[0034] $r_1 r_2 = 0$ *alternating copolymerization* EPEPEPEPEPEPEPEPEPEP

[0035] $r_1 r_2 = 1$ *random* copolymerization PPEPEPEPPEPPPEEPEEPE

[0036] $r_1 r_2 > 1$ *blocky* copolymerization PPPEEEEEEPPPEEEEEPP

10 **[0037]** r_1r_2 represents the reactivity of ethylene and propylene in the copolymer respectively, which are used to describe the characteristic of the catalyst system. r_1r_2 , the product of r_1 and r_2 , represents the distribution of monomers in the main chain of the copolymer.

[0038] A "catalyst system" is a combination comprising at least one catalyst compound and at least one activator. When "catalyst system" is used to describe such a pair before activation, it means the inactivated catalyst complex (precatalyst) together with an activator and, optionally, a co-activator. When it is used to describe such a pair after activation, it means the activated complex and the activator or other charge-balancing moiety. The transition metal compound may be neutral as in a precatalyst, or a charged species with a counter ion as in an activated catalyst system. For the purposes of this invention and the claims thereto, when catalyst systems are described as comprising neutral stable forms of the components, it is well understood by one of ordinary skill in the art, that the ionic form of the component is the form that reacts with the monomers to produce polymers. A polymerization catalyst system is a catalyst system that can polymerize monomers to polymer. In some embodiments, the catalyst may be a post- metallocene catalyst.

[0039] As discussed above, random copolymers (RCPs) of propylene and ethylene with high stiffness are useful for the production of expanded bead foam (EPPs). Further, EPPs may be made from RCPs with a C2 content approximately 3%, flexural modulus 650-750 MPa, and melting temperature (T_m) ~147 °C (e.g., Ref. Mat. 2, Ref. Mat. 3). In order to increase foaming throughput, it is presently recognized that it is desirable to form resins having a lower T_m (e.g., less than 150°C,

or less than 140°C), which may improve the processability of the foams. For example, it may be advantageous to form EPPs that have a lower T_m to lessen the steam pressure in a steam chest used to hold the pre-expanded beads that come out of the autoclave. As such, a decrease in T_m and high mechanical strength of EPP resins will provide more industrial applicable materials.

5 **[0040]** This disclosure relates to compositions, and methods for generating the compositions, that have improved mechanical properties (e.g., stiffness and/or toughness), while also having relatively low melt temperatures (e.g., equal to less than 135°C) resulting in improved processability. In general, the techniques discussed herein include generating random copolymers (RCPs) or resins (e.g., polymer resins, polymeric resins) using a mixture including propylene
10 monomers and ethylene monomers. In particular, it is recognized that it may be advantageous to use the disclosed conditions including one or more of a C2 feed flow rate, a C3 feed flow rate, inlet temperatures, outlet temperatures, catalyst flow rate, activator flow rate, or a combination thereof, to obtain a composition having an ethylene monomer content that is between approximately 2% and approximately 7% by weight in the presence of a catalyst as described
15 herein. In particular, the conditions may provide compositions having a combination of mechanical properties (e.g., flexural modulus greater than 600 MPa) and melt temperatures (e.g., less than 140°C) that are difficult to obtain or otherwise unobtainable through certain techniques. At least in some instances, the RCPs may also have a melt flow rate that is between 3 to 12 g/10min. In any case, the disclosed RCPs (e.g., resins) may be used to produce a polymeric foam
20 (e.g., polymer foam) via techniques such as expanded bead polystyrene (EPS) techniques. Further, the disclosed RCPs may be used to produce a polymeric foam with expanded bead foam (EPP) techniques, which may be more efficient and/or lower energy foaming processes as compared to certain foaming processes.

[0041] Reference is now made to the embodiments illustrated in FIGS. 1-4 wherein like
25 numerals are used to designate like parts throughout.

[0042] FIG. 1 is a flow diagram of a method 10 for synthesizing the RCPs or resins using a catalyst platform (e.g., catalyst and activator) in accordance with certain embodiments of the present disclosure. As shown, the method 10 generally includes providing ethylene 12 (e.g., an ethylene feedstock) and propylene 14 (e.g., a propylene feedstock) in the presence of a catalyst 16
30 and activator 18 (e.g., the catalyst platform 20) to produce an ethylene-propylene (EP) composition 22 (e.g., a RCP including ethylene and polypropylene) and, at least in some instances, forming a resin (e.g., an expanded bead foam) 24 using the EP composition 22. Although the

discussion of FIG. 1 relates to ethylene and propylene, it should be noted that the disclosed techniques may also be used to generate compositions based on ethylene and C₄+ olefins. For example, EP composition 22 may be a C₂-C₄ composition, C₂-C₅ composition, C₂-C₆ composition, etc. As described here, the resin may include advantageous properties, or combinations of properties, such as melting temperature (T_m), crystallization temperature (T_c), melt flow rate (MFR), and flexural modulus at 1% Secant. In some embodiments, and as described in more detail with respect to FIGS. 8 and 9, the EP composition 22 may include a comonomer that is distributed uniformly, orthogonally, or conventionally within the EP composition 22.

[0043] Referring to the method 10, at block 26, ethylene 12 and propylene 14 are contacted in the presence of a catalyst 16 and/or catalyst platform 20 (e.g., the catalyst 16 and the activator 18). In some embodiments, block 26 may include contacting the propylene feedstock and the ethylene feedstock in the presence of the catalyst at a temperature between approximately 70°C and approximately 190°C. In some embodiments, contacting the ethylene 12 and propylene 14 in the presence of the catalyst 16 and/or the catalyst platform 20 may include providing a flow of a feedstock (e.g., a C₂ feed flow rate and a C₃ feed flow rate) including the ethylene 12 and propylene 14 over a solid support formed of the catalyst 16 and/or catalyst platform 20. For example, the catalyst 16 and/or catalyst platform 20 may be stored or otherwise contained in a reaction vessel, and the feedstock including the ethylene 12 and the propylene 14 may be provided, flowed, or otherwise directed into the reaction vessel including the catalyst 16 and/or catalyst platform 20. In another embodiment, a low ethylene 12 feed rate increases the rate of ethylene 12 conversion. The rapid consumption of ethylene 12 leaves the reactor with a low concentration of ethylene 12, which promotes the incorporation of propylene 14 monomers that are inserted sequentially into EP composition 22. Compression molding was performed for each resin. The resins were compression molded at 185°C for 10 min with 2000 PSI of pressure. Then, the samples were quenched in a water bath and dried for further characterizations and processes. In some embodiment, the EP composition 22 may be formed using one or more reactors that are connected in series or in parallel.

[0044] The art of producing foam structures is known, especially for styrenic compositions. Articles comprising the herein described polymeric foam; or foamed articles comprising the polymeric foam of the present disclosure may take physical configurations known in the art, such as regular or irregular molded items. Other useful forms of foamed or foamable objects known in the art include expandable or foamable particles, moldable foam particles, or beads, and articles formed by expansion and/or consolidation and fusing of such particles. In some embodiments, the

polymeric foam described herein is an expanded polypropylene-based bead foam. In
embodiments, the expanded polypropylene-based bead foam is a closed-cell bead foam. Articles
manufactured from polymer bead foams comprise numerous foamed particles, which can be
welded together into three dimensionally shaped products; for example, lightweight parts with
5 complex geometries and a high dimensional accuracy. In some embodiments, said expanded
polypropylene-based bead foam (e.g., as a polymeric foam) can be molded or welded together via
steam-chest molding machine. To facilitate said molding or welding, it is beneficial for the
expanded polypropylene-based bead foam to have a suitable double crystal melting peak
comprising a high and a low temperature melting peaks. Melting of low-temperature peak crystals
10 (T_m-low) contribute to fusing and sintering of individual beads. Unmolten high-temperature peak
crystals (T_m-high) help to preserve overall cellular morphology and dimensional stability of a
molded expanded polypropylene-based bead foam product. A narrow processing window between
the two melting peaks can pose a challenge when setting a processing steam temperature during
the molding process in steam-chest molding machine. A slight variation in steam temperature
15 could cause T_m-high crystals to be affected, which may impact the overall cellular morphology
of the beads, causing shrinkage of the molded expanded polypropylene-based bead foam product.

[0045] Tables 1 and 2 show example process conditions for performing block 26 of the method
10 of FIG. 1. In general, Tables 1 and 2 show a type of the catalyst 16 and activator 18 that may
be used to produce the EP composition 22. Additionally, Tables 1 and 2 show examples of flow
rates of the catalyst 16 (e.g., catalyst flow rate) and examples of flow rates of the activator 18 (e.g.,
20 activator flow rate). The first type of conditions (e.g., ‘Reference Material 1(Ref. Mat. 1)’, ‘Ref.
Mat. 2’, ‘Ref. Mat. 3’, or ‘Ref. Mat. 4’) correspond to a baseline composition. The second type
of conditions (e.g., ‘Experimental Material 1 (Ex. Mat. 1’ or ‘Ex. Mat. 2 – Ex. Mat. 16’)
correspond to the disclosed EP composition 22.

25

]	Ref. Mat. 1	Ex. Mat. 1	Ex. Mat. 2	Ex. Mat. 3	Ex. Mat. 4	Ex. Mat. 5	Ex. Mat. 6
Catalyst	Cat. 1	Cat. 2	Cat. 2	Cat. 2	Cat. 2	Cat. 2	Cat. 2
Activator	N-D9	D4	D4	D4	D4	D4	D4
Catalyst Flow Rate (kg/hr)	10.4	0.0043	0.0046	0.0043	0.0037	0.0038	0.0037
Activator Flow Rate (kg/hr)	10.1	0.015	0.015	0.016	0.016	0.016	0.014
Catalyst Efficiency (kg/g)	830	1,368	1,366	257	292	291	269
Reactor Inlet Temperature (°C)	19.0	17.8	14.4	26.24	25.69	25.87	25.25
Reactor Outlet Temperature (°C)	81.3	126	126	89.91	89.99	89.91	89.93
Reactor Pressure (psig)	1740	1595	1595	1600	1600	1600	1600
C2 Feed (kg/hr)	2413	0.5	0.3	0.103	0.103	0.103	0.103
C3 Feed (kg/hr)	95385	13.490	13.492	5.840	5.841	5.840	5.839

C2/C3 Feed (kg/kg)	0.025	0.037	0.022	0.018	0.018	0.018	0.018
Hydrogen Feed (sccm)	0	0	0	200	200	200	200
Cement Conc. (wt.%)	7.2	13.9	14.6	6.04	5.94	6.02	6.16
H ₂ /C3 Feed (wppm)	0	0	0	10443	10441	10441	10442
C2 Conversion (%)	54.0	92.7	84.1	37.7	42.5	39.7	28.2
C3 Conversion (%)	30.4	40.6	44.0	18.4	18.0	18.3	18.9
C2 In-reactor Concentration (M)	0.22	0.086	0.113	0.35	0.32	0.34	0.40
C3 In-reactor Concentration (M)	15.4	18.812	17.802	19.77	18.23	19.15	22.79

Table 1 shows example reaction conditions for producing the disclosed random copolymers.

Condition	Ref. Mat. 1	Ex. Mat. 7	Ex. Mat. 8	Ex. Mat. 9	Ex. Mat. 10	Ex. Mat. 11	Ex. Mat. 12	Ex. Mat. 13	Ex. Mat. 14	Ex. Mat. 15	Ex. Mat. 16
Catalyst	Cat. 1	Cat. 2	Cat. 2	Cat. 2	Cat. 2	Cat. 2	Cat. 2	Cat. 2	Cat. 2	Cat. 2	Cat. 2
Activator	Act. 1	Act. 2	Act. 2	Act. 2	Act. 2	Act. 2	Act. 2	Act. 2	Act. 2	Act. 2	Act. 2
Catalyst Flow Rate (kg/hr)	10.4	0.005	0.005	0.004	0.004	0.004	0.004	0.004	0.003	0.003	0.004
Activator Flow Rate (kg/hr)	10.1	0.006	0.006	0.005	0.005	0.005	0.005	0.005	0.004	0.004	0.004
Catalyst Efficiency (kg/g)	830	1,923	1,912	2,380	2,443	2,442	2,468	2,453	1,992	1,872	1,850
Reactor Inlet Temperature (°C)	19	20.0	20.1	20.1	20.1	20.0	20.1	19.9	14.7	14.7	14.6
Reactor Outlet Temperature (°C)	81.3	118.0	118.0	112.1	110.3	110.0	110.2	109.9	105.0	105.0	105.0
Reactor Pressure (psig)	1740	1600	1600	1600	1600	1600	1601	1600	1600	1600	1600
C2 Feed (kg/hr)	2413	0.730	0.668	0.658	0.504	0.504	0.504	0.504	0.201	0.201	0.201
C3 Feed (kg/hr)	95385	25.672	25.785	28.898	29.194	29.192	29.191	29.193	15.054	15.054	15.053
C2/C3 Feed (kg/kg)	0.025	0.028	0.026	0.023	0.017	0.017	0.017	0.017	0.013	0.013	0.013
Hydrogen Feed (sccm)	0	2	1	263	359	500	500	500	350	400	400
Cement Conc. (wt.%)	7.2%	12.7%	12.7%	11.9%	11.7%	11.7%	11.7%	11.6%	11.8%	11.8%	11.8%
H ₂ /C3 Feed (wppm)	0	0.4	0.3	49.1	66.3	92.4	92.4	92.4	125.4	143.3	143.3
C2 Conversion (%)	54%	76.5%	80.6%	66.1%	66.6%	75.9%	72.1%	81.5%	94.6%	97.7%	97.7%
C3 Conversion (%)	30.4%	36.7%	36.6%	32.7%	32.7%	32.3%	32.4%	32.1%	42.3%	42.2%	42.2%
C2 In-reactor Concentration (M)	0.22	0.045	0.034	0.055	0.041	0.030	0.034	0.023	0.004	0.002	0.002
C3 In-reactor Concentration (M)	15.4	2.821	2.836	3.197	3.199	3.217	3.210	3.224	2.222	2.227	2.225
[C2]/[M]	0.021	0.016	0.012	0.017	0.013	0.009	0.011	0.007	0.002	0.001	0.001

Table 2 shows example reaction conditions for producing the disclosed random copolymers.

[0046] For example, the catalyst 16 in Tables 1 and 2 may include Ziegler-Natta catalysts, or titanium-based catalyst systems. In particular, the first type of catalyst (e.g., ‘Catalyst 1 or Cat. 1’) corresponds to a baseline catalyst system, wherein the catalyst comprises a metallocene catalyst, while the second type of catalyst (e.g., ‘Catalyst 2 or Cat. 2’) corresponds to the catalyst 16 described above, wherein the catalyst 16 comprises a post-metallocene catalyst. The catalyst flow rate in Tables 1 and 2 for the catalyst 16 may range from about 0.0027 kilograms/hour (kg/hr) to about 0.0063 kg/hr. For example, the flow rate for the catalyst 16 may be between 0.0030 kg/hr

to 0.060 kg/hr, between 0.0035 kg/hr to 0.0055 kg/hr, between 0.0040 kg/hr to 0.0050 kg/hr, or the flow rate for the catalyst 16 may be about 0.0028 kg/hr, about 0.0030, about 0.0032, about 0.0034, about 0.0036, about 0.0038, about 0.004, about 0.0042, about 0.0044, about 0.0046, about 0.0048, about 0.0050, about 0.0052, about 0.0054, about 0.0056, about 0.0058, about 0.0060, or about 0.0062. The flow rate of the baseline catalyst system is approximately 10 kg/hr (e.g., about 10.1, 10.2, 10.3, 10.4, or 10.5). As such, the flow rate of the catalyst 16 is relatively lower as compared to the baseline catalyst system due to an increase in catalytic efficiency.

[0047] The activator 18 in Tables 1 and 2 may include an external electron donor. The external electron donor system may have at least two electron donors, wherein the external electron donors are organosilanes. In particular, the first type of activator (e.g., 'Activator 1 or Act. 1') corresponds to a baseline activator, while the second type of activator (e.g., 'Activator 2 or Act. 2') corresponds to the activator 18 described above. The activator flow rate in Tables 1 and 2 for the Act. 2 or activator 18 may range from about 0.001 kilograms/hour (kg/hr) to about 0.02 kg/hr. For example, the flow rate for the activator 18 may be between 0.002 to 0.018 kg/hr, between 0.004 to 0.016 kg/hr, between 0.006 to 0.014 kg/hr, between 0.008 to 0.012 kg/hr, about 0.003, about 0.005, about 0.007, about 0.009, about 0.011, about 0.013, about 0.015, or about 0.017 kg/hr. The flow rate of the baseline activator or Act. 1 is approximately 10 kg/hr (e.g., about 10.1, 10.2, 10.3, 10.4, or 10.5 kg/hr). As such, the flow rate of the Act. 2 is relatively lower as compared to Act. 2, due to an increase in catalytic efficiency of the catalyst system.

[0048] Tables 1 and 2 also show the catalyst efficiency. For example, the catalyst efficiency of the catalyst 16 of the present disclosure is between about 250 kg/g to about 3600 kg/g. For example, the catalyst efficiency of the catalyst 16 may be between 350 to 3550 kg/g, 450 to 3450 kg/g, 550 to 3350 kg/g, 650 to 3250 kg/g, 750 to 3150 kg/g, 850 to 3050 kg/g, 950 to 2950 kg/g, 1050 to 2850 kg/g, 1150 to 2750 kg/g, 1250 to 2650 kg/g, 1350 to 2550 kg/g, 1450 to 2450 kg/g, 1550 to 2350 kg/g, 1650 to 2250 kg/g, 1750 to 2150 kg/g, or 1850 to 2050 kg/g. In some embodiments, the catalyst efficiency may be about 250, about 300, about 350, about 400, about 450, about 500, about 550, about 600, about 650, about 700, about 750, about 800, about 850, about 900, about 950, about 1000, about 1050, about 1100, about 1150, about 1200, about 1250, about 1300, about 1350, about 1400, about 1450, about 1500, about 1550, about 1600, about 1650, about 1700, about 1750, about 1800, about 1850, about 1900, about 1950, about 2000, about 2050, about 2100, about 2150, about 2200, about 2250, about 2300, about 2350, about 2400, about 2450, about 2500, about 2550, about 2600, about 2650, about 2700, about 2750, about 2800, about 2850, about 2900, about 2950, about 3000, about 3050, about 3100, about 3150, about 3200, about 3250,

about 3300, about 3450, about 3500, about 3550, or about 3600 kg/g. Further, Tables 1 and 2 show a catalyst efficiency of the baseline catalyst system is approximately 830 kilograms/grams (kg/g) (e.g., about 800, 810, 820, 830, 840, or 850 kg/g).

[0049] Further, Tables 1 and 2 also show the reactor inlet temperature and the reactor outlet temperature in Celsius (°C). In general, the reactor inlet temperature may correspond to the temperature of a fluid entering a reaction vessel that performs block 26. In a generally similar manner, the reactor outlet temperature may correspond to the temperature of a fluid exiting the reaction vessel that performs block 26. In some embodiments, the reactor inlet temperature of the present disclosure may be between 10°C and 30°C. For example, the reactor inlet temperature of the present disclosure for EP composition 22 may be between 11°C and 29°C, 12°C and 28°C, 13°C and 27°C, about 11°C, about 12°C, about 13°C, about 14°C, about 15°C, about 16°C, about 17°C, about 18°C, about 19°C, about 20°C, about 21°C, about 22°C, about 23°C, about 24 °C, about 25°C, about 26°C, about 27°C, about 28°C, about 29°C, or about 30°C. The reactor inlet temperature of baseline composition may be between 15°C and 20°C, about 15°C, about 16°C, about 17°C, about 18°C, about 19°C, or about 20°C. In some embodiments, the reactor outlet temperature of the present disclosure for EP composition 22 may be between 75°C and 130°C. For example, the reactor outlet temperature of the present disclosure may be between 76°C and 129°C, 77°C and 128°C, 78°C and 127°C, 79°C and 128°C, 80°C and 130°C, about 81°C, about 82°C, about 83°C, about 84°C, about 85°C, about 86°C, about 87°C, about 89°C, about 90°C, about 125 °C, about 126°C, about 127°C, about 128°C, or about 129°C. The reactor outlet temperature of baseline composition may be between 80°C and 85°C, about 80°C, about 81°C, about 82°C, about 83°C, about 84°C or about 85°C.

[0050] Further, Tables 1 and 2 show the reactor pressure for performing the reaction at block 26 of FIG. 1. According to Tables 1 and 2, the reactor pressures in pounds per square inch gauge (psig) may be between 1500 psig and 1800 psig. For example, the reactor pressure of the present disclosure for EP composition 22 may be between 1550 psig and 1750 psig, 1560 psig and 1740 psig, about 1525, about 1550, about 1575, about 1600, about 1625, about 1650, about 1675, about 1700, about 1725, about 1750, about 1775, or about 1800. The reactor pressure of the baseline composition may be between 1700 psig to 1750 psig, about 1700 psig, about 1710 psig, about 1720 psig, about 1730 psig, about 1740 psig, or about 1750 psig.

[0051] Further still, Tables 1 and 2 show example feed flow rates for providing ethylene 12 (e.g., a C2 feed flow rate) to a reactor in accordance with block 26 of FIG. 1. In particular, the first

type of C2 feed flow rate (e.g., 'Ref. Mat. 1') corresponds to a baseline composition, while the second type of C2 feed flow rate (e.g., 'Ex. Mat. 1 – Ex. Mat. 16') corresponds to the C2 feed flow rate described above. The C2 flow rate for the ethylene 12 ('Ex. Mat. 1 – Ex. Mat. 16') may range from about 0.0 kilogram/hour (kg/hr) to 1.0 kg/hr. For example, the flow rate for the C2 feed ethylene 12 may be between 0.1 kg/hr to 0.9 kg/hr, 0.2 kg/hr to 0.8 kg/hr, 0.3 kg/hr to 0.7 kg/hr, 0.4 kg/hr to 0.6 kg/hr, about 0.1, about 0.2, about 0.3, about 0.4, about 0.5, about 0.6, about 0.7, about 0.8, or about 0.9. The C2 feed flow rate for the baseline composition ('Ref. Mat. 1') is approximately 2400 kg/hr (e.g., about 2402, about 2404, about 2406, about 2408, about 2410, about 2412, or about 2414). As such, the flow rate of C2 feed (e.g., of the ethylene 12) is relatively lower as compared to the baseline composition, as it is with respect to the flow rate of the catalyst.

[0052] Further, Tables 1 and 2 show the feed flow rates for providing propylene 14 (e.g., a C3 feed flow rate) to a reactor in accordance with block 26 of FIG. 1. In particular, C3 feed flow rate of the first example conditions (e.g., 'Ref. Mat. 1') corresponds to a baseline composition, while the second type of C3 feed flow rate (e.g., 'Ex. Mat. 1 – Ex. Mat. 16') corresponds to the C3 feed flow rate described above. The C3 flow rate for the propylene 14 ('Ex. Mat. 1 – Ex. Mat. 16') may range from about 5.000 kilogram/hour (kg/hr) to 30.000 kg/hr. For example, the flow rate for the C3 feed propylene 14 may be between 9 kg/hr to 26 kg/hr, 13 kg/hr to 22 kg/hr, 17 kg/hr to 18 kg/hr, about 5, about 7, about 9, about 11, about 13, about 15, about 17, about 19, about 21, about 23, about 25, about 27, or about 29. The C3 feed flow rate for the baseline composition ('Ref. Mat. 1') may be approximately 95300 kg/hr (e.g., about 95310, about 95320, about 95330, about 95340, about 95350, about 95360, about 95370, about 95380, about 95390, or about 95400). As such, the flow rate of C3 feed propylene 14 is relatively lower as compared to the baseline composition, as it is with respect to the flow rate of the catalyst.

[0053] Tables 1 and 2 also show the C2/C3 feed amounts related to the amounts of ethylene 12 and propylene 14 provided to a reaction in accordance with block 26 of FIG. 1. In some embodiments, the C2/C3 feed amounts in kilogram (of C2)/kilogram (of C3) (kg/kg) may be between 0.00 kg/kg and 0.060 kg/kg. For example, the C2/C3 feed amounts in the present disclosure for EP composition 22 may be between 0.005 kg/kg and 0.055 kg/kg, 0.01 kg/kg and 0.045 kg/kg, 0.015 kg/kg and 0.040 kg/kg, 0.020 kg/kg and 0.035, 0.025 kg/kg and 0.030 kg/kg, about 0.005 kg/kg, about 0.010, about 0.015, about 0.020, about 0.025, about 0.030, about 0.035, about 0.040 kg/kg, about 0.045, about 0.050, about 0.055, or about 0.060 kg/kg. The C2/C3 feed flow rates for the baseline composition may be between 0.020 kg/kg and 0.030 kg/kg, about 0.021, about 0.023, about 0.025, about 0.027, or about 0.029.

[0054] Tables 1 and 2 also show the hydrogen (H₂) feed amounts in standard cubic centimeter per minute (sccm). In general, the feed amounts correspond to an amount of hydrogen that may be provided along with the ethylene 12 and the propylene 14 in the presence of the catalyst 16 (e.g., or catalyst system 20). The H₂ feed amounts can be tuned accordingly to produce polymers at a specific molecular weight. In some embodiments, the hydrogen feed amounts in the present disclosure for EP composition 22 may be between 0 and 550 sccm. For example, the hydrogen feed amounts in the present disclosure may be between 50 sccm and 500 sccm, 100 sccm and 450 sccm, 150 sccm and 400 sccm, 200 sccm and 350 sccm, 250 sccm and 300 sccm, about 25 sccm, about 0 sccm, about 50, about 75, about 100, about 125, about 150, about 175, about 200, about 225, about 250, about 275, about 300, about 325, about 350, about 375, about 400, about 425, about 450, about 475, about 500, about 525, or about 550 sccm. The hydrogen feed amount in the baseline composition is 0 sccm.

[0055] Tables 1 and 2 also show examples of cement concentration in weight percent (wt.%). In general, cement concentration refers to an amount of polymer that is in a reactor. According to Tables 1 and 2, cement concentration amounts may be between 5 wt.% and 15 wt.%. For example, the cement concentration in the present disclosure for EP composition 22 may be between 6 wt.% and 14 wt.%, 7 wt.% and 13 wt.%, 8 wt.% and 12 wt.%, about 5, about 6, about 7, about 8, about 9, about 10, about 11, about 12, about 13, about 14, or about 15. Further, the cement concentration for the baseline composition may be between 7.0 wt % and 7.5 wt.%, about 7.0, about 7.1, about 7.2, about 7.3, about 7.4, or about 7.5.

[0056] Tables 1 and 2 also show examples of H₂/C₃ feed amounts in weight parts per million (wppm). According to Tables 1 and 2, H₂/C₃ feed amounts may be between 0 wppm and 10500 wppm. For example, H₂/C₃ feed amounts in the present disclosure for EP composition 22 may be between 100 wppm and 10400 wppm, 200 wppm and 10300 wppm, 300 wppm and 10200 wppm, 400 wppm and 10100 wppm, 500 wppm and 10000 wppm, about 100 wppm, about 200, about 300, about 400, about 500, about 600, about 700, about 800, about 900, about 1000, about 2000, about 3000, about 4000, about 5000, about 6000, about 7000, about 8000, about 9000, or about 10000. Further, the H₂/C₃ feed amounts in the baseline composition is 0 wppm.

[0057] Tables 1 and 2 also show examples of C₂ conversion in percent (%). In general, the C₂ conversion corresponds to an amount of ethylene 12 that is consumed to form the EP composition 22. According to Tables 1 and 2, C₂ conversions are greater than 25 %. For example, C₂ conversions in the present disclosure may be between 25 to 90%, 25 to 80%, 30 to 70%, 40 to

60%, greater than 25%, greater than 30%, greater than 35%, greater than 50%, greater than 60%, greater than 70%, greater than 70%, greater than 90%, or greater than 95%. Further, C2 conversions for the baseline composition are greater than 50%. Tables 1 and 2 also show examples of C3 conversion in percent (%). In general, the C3 conversion corresponds to an amount of C3 propylene monomer 14 that is consumed to form the EP composition 22. According to Tables 1 and 2, C3 conversions may be between 15% to 45%. In some embodiments, C3 conversions in the present disclosure may be between 17 to 42%, 19 to 40%, 21 to 39%, 23 to 37%, 25% to 35%, 27% to 33%, 29% to 31%, greater than 15%, greater than 20%, greater than 25%, greater than 30%, greater than 35%, or greater than 40%. Further, C3 conversions for the baseline composition are greater than 30%. As shown in Tables 1 and 2, the C3 conversion is generally lower than the C2 conversion.

[0058] Further, Tables 1 and 2 also show examples of C2 in-reactor concentration in molar (M). According to Tables 1 and 2, C2 in-reactor concentrations may be between 0.000 M to 0.50 M. For example, C2 in-reactor concentrations in the present disclosure for EP composition 22 may be between 0.000 M and 0.50 M, 0.005 M and 0.45 M, 0.01 M and 0.40 M, 0.015 M and 0.3 M, 0.020 M and 0.25 M, 0.025 M and 0.20 M, 0.030 M and 0.15 M, 0.035 M and 0.10 M, 0.040 M and 0.05 M, about 0.002 M, about 0.004, about 0.006, about 0.008, about 0.01, about 0.015, about 0.020, about 0.025, about 0.030, about 0.035, about 0.040, about 0.045, about 0.050, about 0.055, about 0.060, about 0.065, about 0.070, about 0.075, about 0.080, about 0.085, about 0.090, about 0.095, about 0.10, about 0.15, about 0.20, about 0.25, about 0.30, about 0.35, about 0.40, about 0.45, or about 0.50M. For example, C2 in-reactor concentrations for the baseline composition may be between 0.01 M and 0.4 M, about 0, about 0.1, about 0.2, about 0.3, or about 0.4. Tables 1 and 2 also show examples of C3 in-reactor concentration in molar (M). According to Tables 1 and 2, C3 in-reactor concentrations may be between 0 M to 30 M. For example, C3 in-reactor concentrations in the present disclosure for EP composition 22 may be between 0 M and 25 M, 5 M and 20 M, 10 M and 15 M, about 2 M, about 4, about 6, about 8, about 10, about 12, about 14, about 16, about 18, about 20, about 22, about 24, about 26, about 28, or about 30 M. Further, C3 in-reactor concentrations for the baseline composition may be between 15.0 M and 15.5 M, about 15.0, about 15.1, about 15.2, about 15.3, about 15.4, or about 15.5 M.

[0059] Accordingly, Tables 1 and 2 show example conditions corresponding to method 10 of FIG. 1 for production of resins 24. As such, Tables 1 and 2 provide information including catalyst type, catalyst flow rate, and catalyst efficiency. Further, Tables 1 and 2 show activator type, activator flow rate, reaction temperatures, reactor pressures, flow rates of C2 and C3, hydrogen

feed amounts, cement concentration, C2 conversion, C3 conversion, C2 in-reactor concentration, and C3-in reactor concentration.

[0060] Table 2 also shows the ratio ($[C2]/[M]$) of the concentration of ethylene 12 (C2) monomers divided by the total concentration of ethylene 12 and propylene 14 monomers (M). In an embodiment, the $[C2]/[M]$ in the present disclosure for EP composition 22 may be between 0 and 0.020, 0.004 and 0.016, 0.008 and 0.012, about 0.002, about 0.004, about 0.006, about 0.008, about 0.010, about 0.012, about 0.014, about 0.016, about 0.018, or about 0.020. Further, the $[C2]/[M]$ ratio for the baseline composition may be between 0.020 and 0.025, about 0.020, about 0.021, about 0.022, about 0.023, about 0.024, or about 0.025. In general, the $[C2]/[M]$ values for EP composition 22 are lower than the $[C2]/[M]$ value for the baseline composition, which is advantageous as decreasing the relative concentration of C2 creates longer runs of propylene between ethylene segments and may lead to improved crystallinity with higher melting temperatures.

[0061] As discussed herein, the EP composition 22 and/or resin 24 may have a combination of properties (e.g., melt temperature and flexural strength) that are distinct or otherwise unobtainable by certain methods. The resin 24 has a Mw between 200,000 g/mol to about 3000,000 g/mol, Mn between 100,000 g/mol and 150,000 g/mol, a PDI from 1.5 to 5 or 1.9 and 2.4. In some embodiments, the disclosed EP composition 22 and/or resin 24 (e.g., propylene-based polymer or otherwise alkene-based) may have a PDI of 1.8 to 5 and an Mz/Mw of 1.5 to 4.0. The chemical composition of the resin 24 may be characterized by the blocks of ethylene and propylene using ¹³C-NMR. With this in mind, Tables 3 and 4 show mole fractions of the resin 24 produced in accordance with the present disclosure in comparison to certain compositions. It should be noted that although Tables 3 and 4 refer to characterization of the blocks of the resin 24, the characterization may also apply to certain compositions of the EP composition 22. In general, “Ex. Mat. 1 – Ex. Mat. 19” correspond to the disclosed resin 24 and/or EP composition 22, while the remaining examples (e.g., ‘Ref. Mat. 1 – Ref. Mat. 3’) correspond to certain baseline compositions.

Condition	Units	Ref. Mat. 1	Ref. Mat. 2	Ref. Mat. 3	Ex. Mat. 1	Ex. Mat. 17	Ex. Mat. 3	Ex. Mat. 4	Ex. Mat. 5	Ex. Mat. 6
[EEE]	mol fraction	0.002	0.004	0.001	0.002	0.003	0.002	0.002	0.002	0.002
[PEE+EEP]	mol fraction	0.006	0.010	0.004	0.020	0.017	0.008	0.007	0.008	0.007

[PEP]	mol fraction	0.053	0.034	0.034	0.065	0.059	0.036	0.036	0.037	0.037
[EPE]	mol fraction	0.006	0.006	0.003	0.015	0.012	0.005	0.004	0.005	0.005
[EPP+PPE]	mol fraction	0.102	0.068	0.070	0.136	0.128	0.077	0.081	0.080	0.082
[PPP]	mol fraction	0.831	0.879	0.887	0.761	0.782	0.873	0.871	0.869	0.868
total regio defects	mole %	0.69	0.0777	0.0358	0.63	0.63	0.60	0.49	0.61	0.53
2,1-E defect	mole %	0.48	0.0138	0.0141	0.40	0.43	0.34	0.30	0.35	0.34
2,1-EE defect	mole %	0.21	0.0640	0.0218	0.23	0.20	0.25	0.18	0.26	0.19
Triad tacticity index from PP (%mm)	% mm	93.2	98.2	98.1	99.4	99.3	98.7	98.6	98.5	99.0
Triad tacticity index from PP and EP (%mm)	% mm	81.0					88.7	88.5	88.1	88.6

Table 3 shows chemical composition of the novel TPE resins in mole fractions (%) by ¹³C-NMR.

Condition	Units	Ref. Mat. 1	Ex. Mat. 7	Ex. Mat. 8	Ex. Mat. 9	Ex. Mat. 10	Ex. Mat. 11	Ex. Mat. 12	Ex. Mat. 13	Ex. Mat. 14	Ex. Mat. 15	Ex. Mat. 16	Ex. Mat. 18	Ex. Mat. 19
[EEE]	mol fraction	0.002	0.003	0.002	0.002	0.002	0.002	0.004	0.006	0.006	0.002	0.008	0.007	0.009
[PEE+EEP]	mol fraction	0.006	0.016	0.014	0.01	0.007	0.008	0.007	0.009	0.006	0.006	0.008	0.027	0.033
[PEP]	mol fraction	0.053	0.058	0.055	0.047	0.037	0.039	0.039	0.04	0.035	0.036	0.038	0.062	0.065
[EPE]	mol fraction	0.006	0.01	0.01	0.007	0.005	0.007	0.005	0.005	0.007	0.006	0.009	0.017	0.020
[EPP+PPE]	mol fraction	0.102	0.122	0.116	0.103	0.085	0.087	0.088	0.086	0.081	0.076	0.083	0.123	0.131
[PPP]	mol fraction	0.831	0.792	0.802	0.83	0.865	0.857	0.859	0.854	0.865	0.874	0.855	0.765	0.742
total regio defects	mole %	0.69	0.525	0.573	0.463	0.435	0.655	0.475	0.611	0.686	0.593	0.813	0.73	0.58
Triad tacticity index from PP (%mm)	%mm	93.2	98.7	99.2	99	98.8	99.9	99.3	99.3		99.2		98.2	97.6
Triad tacticity index from PP and EP (%mm)	%mm	81.0	83.3	84.2	86.2	88.3	88	88.4	88	88.4	89.2	88.9		
n ₁ n ₂		1.165	1.947	1.943	1.906	2.331	2.635	3.064	4.187	4.319	4.763	4.814	2.84	2.96

Table 4 shows chemical composition of the novel TPE resins in mole fractions (%) by ¹³C-NMR.

[0062] In general, the mole fractions correspond to amounts of different blocks (e.g., polymer blocks) within the copolymer (e.g., the resin 24). For example, the blocks shown in Tables 3 and

4 include three ethylene units (EEE), propylene-ethylene-ethylene or ethylene-ethylene-propylene (PEE+EEP), propylene-ethylene-propylene (PEP), ethylene-propylene-ethylene (EPE), ethylene-propylene-propylene or propylene-propylene-ethylene (EPP+PPE), propylene-propylene-propylene (PPP), total regioselectivity defect, and certain ethylene copolymer defects (e.g., 2,1-E defect or 2,1-EE defect). In another embodiment of the invention, the polymers produced herein have regio defects (as determined by ^{13}C NMR), based upon the total propylene monomer. Three types defects are defined to be the regio defects: 2,1-erythro, 2,1-threo, and 3,1 -isomerization as well as a defect followed by ethylene insertion. The structures and peak assignments for these are given in [L. Resconi, et al. (2000), Chem. Rev., v.100, pp. 1253-1345]. The regio defects each give rise to multiple peaks in the carbon NMR spectrum, and these are all integrated and averaged (to the extent that they are resolved from other peaks in the spectrum), to improve the measurement accuracy. The chemical shift offsets of the resolvable resonances used in the analysis are tabulated below. The precise peak positions may shift as a function of NMR solvent choice. The average integral for each defect is divided by the integral for total area (CH₃, CH, CH₂), and multiplied by 100 to determine the total defect concentration, reported as mol% regio defects (also called regio errors). Definition of species (ab and bg) are as defined in Randall in "A Review Of High Resolution Liquid Carbon Nuclear Magnetic Resonance Characterization of Ethylene-Based Polymers", Polymer Reviews, v.29:2, 201-5 pg. 317 (1989). As referred to herein, the sum of the different types of measured regio defects (i.e. 2,1-E + 2,1-EE) may be presented as the "total regio defects" in units of mol%. For example, 2,1-E regio error occurs when a propylene molecule inserts "head-to-head" rather than "head-to-tail" (i.e., the monomer is turned around). In another embodiment, a 2,1-EE regio error occurs when a propylene molecule inserts "head-to-head" rather than "head-to-tail" and also exhibits a stereochemistry error. As shown, [the EEE] mole fractions of the resin 24 may be between about 0.002 to 0.009, approximately 0.002, approximately 0.004, approximately 0.006, approximately 0.008, or approximately 0.009. The [PEE+EEP] mole fractions of the resin 24 may be between 0.001 and 0.035, approximately 0.001, approximately 0.003, approximately 0.005, approximately 0.007, approximately 0.009, approximately 0.011, approximately 0.013, approximately 0.015, approximately 0.017, approximately 0.019, approximately 0.025, or approximately 0.035. In general, the [PEP] mole fractions of the resin 24 may be between 0.03 and 0.07, approximately 0.035, approximately 0.04, approximately 0.045, approximately 0.05, approximately 0.055, approximately 0.06, approximately 0.065, or approximately 0.070. Further, the [EPE] mole fractions of the resin 24 may be between 0.003 and 0.020, approximately 0.003, approximately 0.005, approximately 0.007, approximately 0.009, approximately 0.011, approximately 0.013, approximately 0.015, or approximately 0.020. The

[EPP+PPE] mole fractions of the resin 24 may be between 0.075 and 0.140, approximately 0.080, approximately 0.085, approximately 0.090, approximately 0.095, approximately 0.10, approximately 0.105, approximately 0.110, approximately 0.115, approximately 0.120, approximately 0.125, approximately 0.130, approximately 0.135, or approximately 0.140. The [PPP] mole fractions of the resin 24 may be between 0.7 and 0.9, 0.75 and 0.9, 0.8 and 0.9, 0.8 and 0.85, 0.761 and 0.873, approximately 0.705, approximately 0.725, approximately 0.745, approximately 0.765, approximately 0.785, approximately 0.805, approximately 0.825, approximately 0.845, approximately 0.86, approximately 0.865, approximately 0.885, or approximately 0.90. The total regioisomer defect mole % for the resin 24 may be between 0.40% and 0.85%, 0.45% and 0.80%, 0.50% and 0.75%, approximately 0.40%, approximately 0.45, approximately 0.50, approximately 0.55, approximately 0.60, approximately 0.65, approximately 0.70, approximately 0.75, approximately 0.80, or approximately 0.85%. The 2,1-E-defect mole % for the resin 24 may be between 0.30% and 0.45%, or approximately 0.30%, approximately 0.35, approximately 0.40, or approximately 0.45%. In general, the 2,1-EE-defect mole % for the resin 24 may be between 0.15% and 0.30%, or approximately 0.15%, approximately 0.20, approximately 0.25, or approximately 0.30%. The total meso-meso percent (%mm) from PP may be between 90% to 100%, 92% to 98%, 94% to 96%, approximately 90.2%, approximately 92.2, approximately 94.2, approximately 96.2, approximately 98.2, or approximately 100%. The total meso-meso percent (%mm) from PP and EP may be between 80% to 90%, 82% to 88%, 84% to 86%, approximately 80.5%, approximately 82.5, approximately 84.5, approximately 86.5, approximately 88.5, or approximately 90%.

[0063] The baseline copolymers correspond to Ref. Mat. 1 Ref. Mat. 2, and Ref. Mat. 3. As shown, the [EEE] mole fractions of the baseline copolymers may be between 0.001 and 0.004. The [PEE+EEP] mole fractions of the baseline copolymers may be between 0.004 and 0.010. In general, the [PEP] mole fractions of the baseline copolymers may be 0.030 and 0.055, or approximately 0.035, approximately 0.40, approximately 0.45, approximately 0.50, or approximately 0.055. Further, the [EPE] mole fractions of the baseline copolymers may be between 0.003 and 0.006. Further still, the [EPP+PPE] mole fractions of the baseline copolymers may be between 0.065 and 0.105, or approximately 0.070, approximately 0.075, approximately 0.080, approximately 0.085, approximately 0.090, approximately 0.095, approximately 0.100, or approximately 0.105. The [PPP] mole fractions of the baseline copolymers may be between 0.830 and 0.890, approximately 0.835, approximately 0.840, approximately 0.845, approximately 0.850, approximately 0.855, approximately 0.860, approximately 0.865, approximately 0.870, approximately 0.875, approximately 0.880, approximately 0.885, or approximately 0.890. The

total regioisomer defect mole % for the baseline copolymers may be between 0.0350 and 1.920, approximately 0.5350, approximately 1.035, or approximately 1.535, or approximately 2.035. The 2,1-E-defect mole % for baseline copolymers may be between 0.013 and 0.850, approximately 0.213, approximately 0.413, approximately 0.613, or approximately 0.813. In general, the 2,1-EE-defect mole % for the baseline copolymers may be between 0.020 and 0.21, approximately 0.020, approximately 0.040, approximately 0.060, approximately 0.080, approximately 0.100, approximately 0.120, approximately 0.140, approximately 0.160, approximately 0.180, or approximately 0.20. The total meso-meso percent (%mm) from PP may be between 90 to 100, approximately 90.5, approximately 91.5, approximately 92.5, approximately 93.5, approximately 94.5, approximately 95.5, approximately 96.5, approximately 97.5, approximately 98.5, or approximately 99.5. The total meso-meso percent (%mm) from PP and EP may be approximately 80, approximately 81, approximately 82, or approximately 83.

[0064] Further, Table 2 includes the reactivity ratios (r_1r_2), which describes the rate of incorporation of ethylene monomers (r_1) and propylene monomers (r_2) in blocky copolymer EP composition 22. For example, the r_1r_2 values for EP composition 22 may range between 1.9 and 4.9, 2.2 and 4.7, 2.5 and 4.4, 2.8 and 4.1, 3.1 and 3.8, 3.4 and 3.5, approximately 1.9, approximately 2.1, approximately 2.3, approximately 2.5, approximately 2.7, approximately 2.9, approximately 3.1, approximately 3.3, approximately 3.5, approximately 3.7, approximately 3.9, approximately 4.1, approximately 4.3, approximately 4.5, approximately 4.7, or approximately 4.9. Further, the baseline composition exhibits an r_1r_2 ratio of approximately 1.165 (e.g., about 1.12, about 1.14, about 1.16, or about 1.18). In general, r_1r_2 is used as an indicator of polymer blockiness or monomer clustering. As such, the r_1r_2 values are greater than the baseline composition, which is advantageous as increasing values of r_1r_2 indicate ordered monomer insertions with high polymer blockiness. The blockier polymer composition leads to less breaks in crystallinity and longer runs of polypropylene in the ethylene-propylene copolymer, leading to improved crystallinity with higher melting temperatures.

[0065] Accordingly, Tables 3 and 4 describe the chemical composition of the resins 24 that was determined using carbon-13 nuclear magnetic resonance spectroscopy (^{13}C -NMR). The composition of the resins comprises of different blocks (e.g., polymer blocks) within the copolymer resin.

[0066] As discussed herein, compositions based on the EP composition 22 may have improved mechanical properties while having a relatively low melt temperature and high crystallinity, as

compared to certain baseline polymer resins. Tables 5 and 6 show pilot scale reactor results of the EP composition 22 resins (e.g., resin 24) produced compared to resins formed using the baseline copolymers in accordance with the present disclosure. The first type of conditions (e.g., ‘Ref. Mat. 1 – Ref. Mat. 4’) correspond to a baseline composition. The second type of conditions (e.g., ‘Ex. Mat. 1 – Ex. Mat. 19’) correspond to the disclosed EP composition 22. The third type of conditions (e.g., ‘Ex. Mat. 18 – Ex. Mat. 20’) correspond to the disclosed resin 24.

Condition	Ref. Mat. 1	Ref. Mat. 3	Ref. Mat. 4	Ex. Mat. 1	Ex. Mat. 2	Ex. Mat. 3	Ex. Mat. 4	Ex. Mat. 5	Ex. Mat. 6	Ex. Mat. 18	Ex. Mat. 19	Ex. Mat. 20
MFR (2.16kg, 230°C) g/10min	8.44	7.3	7.5	41	51	3.3	12	4.0	5.7	8.8	8.0	6.4
C ₂ , wt.% (FTIR)	3.8	2.8	Terpolymer	6.3	3.8	3.7	3.4	3.7	3.6	4.8	2.9	3.0
Flex Mod (1% Sec)	378.5	754.9	731.8	235.4	647	805.1	748.5	799.8	864	471	741	729
Young's modulus, (MPa)	433.3	1119	876.2	388.4	790.53	938.5	990.3	994.6	1166.8	631	971	929
Strain at Break (%)	786.6	507.8	796.3	849.2	658.5	645.9	691	699.3	670.4	788.9	768	791
Strength at Break (MPa)	32.2	24.1	31.9	29.4	24.1	27.6	32	33.1	30.7	34.3	33.5	35.4
Strain at Yield (%)	17	12.2	13.8	17	13	14.2	13.3	13.3	12.2	13.3	10.6	11.4
Strength at Yield (MPa)	15	25.9	23.1	14.7	21.3	24.9	24	24.7	26	17.9	23.4	23.0
T _c Peak (°C)	60.5	100.5	90.8	63.9	77.2	98	94.6	96.4	93.1	72.6	80.4	82.3
T _m Peak (°C)	103.9	147.3	135.1	104.8	119.4	130.8	126.3	127.2	126.7	112.7	121.9	124.4

Table 5 shows pilot reactor results of EP composition 22 resins compared to baseline resins.

Condition	Ref. Mat. 1	Ex. Mat. 7	Ex. Mat. 8	Ex. Mat. 9	Ex. Mat. 10	Ex. Mat. 11	Ex. Mat. 12	Ex. Mat. 13	Ex. Mat. 14	Ex. Mat. 15	Ex. Mat. 16	Ex. Mat. 18	Ex. Mat. 19
MFR (2.16kg, 230°C) g/10min	8.44	9.14	8.84	7.34	5.78	8	6.41	8.54	6.51	7.41	6.88	1.0	1.4
C ₂ , (wt.%)	3.8	5.6	5.4	4.4	3.4	3.9	3.7	4.2	3.8	3.5	4.3	8.9	8.4
Flex Mod (1% Sec)	378.5	431	471	564	699	741	729	748	975	1008	1003		
Young's modulus, (MPa)	433.3	534	631	747	938	971	929	956	956	1024	941		
Strain at Break (%)	786.6	770.2	788.9	783.9	749.2	767.5	790.5	764.4	765.2	662.8	780.3		

Strength at Break (MPa)	32.2	31.7	34.3	36.3	35.0	33.5	35.4	33.4	35.2	32.8	35.0		
Strain at Yield (%)	17	14.2	13.3	12.2	11.2	10.6	11.4	11.3	11.7	12.6	11.8		
Strength at Yield (MPa)	15	16.6	17.9	20.0	23.1	23.4	23.0	24.0	25.2	26.0	24.6		
Tc Peak (°C)	60.5	68.93	72.58	75.77	82.62	80.37	82.26	80.97	84.18	89.46	84.16	77.5	79.3
Tm Peak (°C)	103.9	109.71	112.7	117.5	122.95	121.93	123.95	124.35	125.33	125.79	125.24	115.7	115.9

Table 6 shows pilot reactor results of EP composition 22 resins compared to baseline resins.

[0067] In general, Tables 5 and 6 show examples of the melt flow rate (MFR) in grams/10 minutes (g/10min) of EP composition 22 (e.g., ‘Ex. Mat. 1 – Ex. Mat. 19’) is between 1.0 g/10min and 55 g/10min. For example, the MFR for the EP composition 22 may be 5 g/10min to 50 g/10min, 10 g/10min to 45 g/10min, 15 g/10min to 40 g/10min, 20 g/10min to 35 g/10min, 25 g/10min to 30 g/10min, about 5 g/10min, about 10, about 20, about 25, about 30, about 35, about 40, about 45, about 50, or about 55 g/10min.

[0068] Tables 5 and 6 also show the C2 weight percent (wt.%) of EP composition 22 (e.g., ‘Ex. Mat. 1 – Ex. Mat. 19’) determined by Fourier Transform Infrared (FTIR) spectroscopy. In general, the wt.% amounts may be between 2.5 and 20 wt.%. For example, the wt.% for the EP composition 22 is between 3.0 to 19 wt.%, 4 to 18 wt.%, 5 to 17 wt.%, 6 to 16 wt.%, 7 to 15 wt.%, 8 to 14 wt.%, 9 to 13 wt.%, and 10 to 12 wt.%. wt.% In some embodiments, EP composition 22 is about 2.5 wt.%, about 4.5, about 6.5, about 8.5, about 10.5, about 12.5, about 14.5, about 16.5, about 18.5, or about 19.5 wt.%.

[0069] In this embodiment, Tables 5 and 6 show the flexural modulus (flex mod) in (1% Secant) in megapascals (MPa) of EP composition 22 (e.g., ‘Ex. Mat. 1 – Ex. Mat. 19’). In general, the Flex Test was measured using ASTM D790 techniques using specimens that are ISO 37 Type 3 bars, a span on the test fixture of 30 mm, a test speed of 1 inches/minute, and a deflection of the specimens to 1.2% that captures 1% secant modulus. The flex mod values may be between 225 MPa and 1100 MPa. For example, the flex mod values may be between 225 MPa to 1000 MPa, 250 MPa to 900 MPa, 275 MPa to 850 MPa, 325 MPa to 800 MPa, 375 MPa to 750 MPa, 425 MPa to 700 MPa, 475 MPa to 650 MPa, 525 MPa to 600 MPa. In some embodiments, the flex mod is about 240 MPa, about 260, about 280, about 300, about 320, about 340, about 360, about 380, about 400, about 420, about 460, about 480, about 500, about 520, about 540, about 560, about 580, about 600, about 620, about 640, about 660, about 680, about 700, about 720, about 740, about 760, about 780, about 800, about 820, about 840, about 860 MPa, about 880, about 900

MPa, about 920, about 940, about 960, about 980, about 1000, about 1020, about 1040, about 1060, about 1080, or about 1100 MPa.

[0070] Further, Tables 5 and 6 show the Young's modulus in megapascals (MPa) of EP composition 22 (e.g., 'Ex. Mat. 1 – Ex. Mat. 19'). In general, the Tensile Test was measured using
5 ASTM D638 techniques using specimens that are ISO 37 Type 3 bars, a span on the test fixture of 30 mm, a test speed of 2 inches/minute, and a 1 kilo Newton (kN) load cell. The Young's modulus values may be between 350 MPa and 1200 MPa. For example, the Young's modulus values may be between 400 MPa to 1100 MPa, 450 MPa to 1050 MPa, 500 MPa to 1000 MPa, 550 MPa to 950 MPa, 600 MPa to 900 MPa, 550 MPa to 850 MPa, 500 MPa to 800 MPa, 450
10 MPa to 750 MPa, 400 MPa to 700 MPa, 350 MPa to 600 MPa. In some embodiments, the Young's modulus is about 375 MPa, about 425, about 475, about 525, about 575, about 625, about 675, about 725, about 775, about 825, about 875, about 925, about 975, about 1025, about 1075, about 1125, or about 1175 MPa.

[0071] Table 5 further shows the strain at break in percent (%) of EP composition 22 (e.g., 'Ex. Mat. 1 – Ex. Mat. 19'). The strain at break values may be between 600% and 900%. For example,
15 the strain at break values may range between 625% to 875%, 650% to 850%, 675% to 825%, 700 to 800%, 725 to 775%. In some embodiments, the EP composition 22 is about 620%, 640, 660, about 680, about 700, about 720, about 740, about 760, about 780, about 800, about 820, about 840, 860, 880, or about 900%. Table 3 also shows the strength at break in megapascals (MPa) of
20 EP composition 22 (e.g., 'Ex. Mat. 1 – Ex. Mat. 19'). The strength at break values may be between 20 MPa and 37 MPa. For example, the strength at break values may range between 21 MPa to 34 MPa, 22 MPa to 33 MPa, 23 MPa to 32 MPa, about 24 MPa to 31 MPa, about 25 MPa to 30 MPa, about 26 MPa to 29 MPa, or about 27 MPa to 28 MPa. In some embodiments, the strength at break values are about 20.5 MPa, about 21.5, about 22.5, about 23.5, about 24.5, about 25.5, about
25 26.5, about 27.5, about 28.5, about 29.5, about 30.5, about 31.5, about 32.5, about 33.5, about 34.5, about 35.5, or about 36.5 MPa.

[0072] In this embodiment, Table 5 also shows the strain at yield in percent (%) of EP composition 22 (e.g., 'Ex. Mat. 1 – Ex. Mat. 19'). The strain at yield values may be between 10% and 20%. For example, the strain at yield values may range between 11% to 19%, 12% to 18%,
30 13% to 17%, 14% to 16%, about 10.2%. In some embodiments, the strain at yield values may be about 11.2%, about 12.2, about 13.2, about 14.2, about 15.2, about 16.2, about 17.2, about 18.2, or about 19.2%. Table 3 also shows the strength at yield in megapascals (MPa) of EP composition

22 (e.g., 'Ex. Mat. 1 – Ex. Mat. 19'). The strength at yield values may be between 12 MPa and 28 MPa. For example, the strength at yield values may range between 13 MPa to 27 MPa, 14 MPa to 26 MPa, 15 MPa to 25 MPa, 16 MPa to 24 MPa, 17 MPa to 23 MPa, 18 MPa to 22 MPa, 19 MPa to 21 MPa. In some embodiments, the strength at yield is about 12.6 MPa, about 13.6, about 14.6, about 15.6, about 16.6, about 17.6, about 18.6, about 19.6, about 20.6, about 21.6, about 22.6, about 23.6, about 24.6, about 25.6, about 26.6, or about 27.6 MPa.

[0073] Tables 5 and 6 also show the crystallization temperature (T_c) peak ($^{\circ}\text{C}$) of EP composition 22 (e.g., 'Ex. Mat. 1 – Ex. Mat. 19'). The T_c peak values may be between 60 to 100 ($^{\circ}\text{C}$). For example, the T_c peak values may range between 65 $^{\circ}\text{C}$ to 95 $^{\circ}\text{C}$, 70 $^{\circ}\text{C}$ to 90 $^{\circ}\text{C}$, 75 $^{\circ}\text{C}$ to 85 $^{\circ}\text{C}$, about 60 $^{\circ}\text{C}$, about 62, about 64, about 66, about 68, about 70, about 74, about 76, about 78, about 80, about 82, about 84, about 86, about 88, about 90, about 92, about 94, about 96, or about 98 $^{\circ}\text{C}$. Further, Tables 5 and 6 show the melting temperature (T_m) peak ($^{\circ}\text{C}$) of EP composition 22 (e.g., 'Ex. Mat. 1 – Ex. Mat. 19'). The T_m peak values may be between 70 to 135 ($^{\circ}\text{C}$). For example, the T_m peak values may range between 75 $^{\circ}\text{C}$ to 130 $^{\circ}\text{C}$, 80 $^{\circ}\text{C}$ to 125 $^{\circ}\text{C}$, 85 $^{\circ}\text{C}$ to 120 $^{\circ}\text{C}$, 90 $^{\circ}\text{C}$ to 115 $^{\circ}\text{C}$, 95 $^{\circ}\text{C}$ to 110 $^{\circ}\text{C}$, or 100 $^{\circ}\text{C}$ to 105 $^{\circ}\text{C}$. In some embodiments, the T_m value is about 70 $^{\circ}\text{C}$, about 72, about 74, about 76, about 78, about 80, about 82, about 84, about 86, about 88, about 90, about 92, about 94, about 96, about 98, about 100, about 102, about 104, about 106, about 108, about 110, about 112, about 114, about 116, about 118, about 120, about 122, about 124, about 126, about 128, about 130, about 132, or about 134 $^{\circ}\text{C}$.

[0074] Tables 5 and 6 show the melt flow rate (MFR) in grams/10 minutes (g/10min) of the baseline copolymers (e.g., 'Ref. Mat. 1 – Ref. Mat. 4'). The MFR values may be between 7.0 g/10min and 8.5 g/10min. For example, the MFR for the baseline polymers may be about 7.25 g/10min, about 7.45, about 7.65, about 7.85, about 8.05, about 8.25, or about 8.45 g/10min.

[0075] In general, Tables 5 and 6 also show the C2 weight percent (wt.%) of the baseline copolymer (e.g., 'Ref. Mat. 1 – Ref. Mat. 4') acquired with FTIR. In general, the wt.% amounts may be between 2.5 to 4.0 wt.%. For example, the wt.% for the baseline copolymers may be about 2.5, about 2.6, about 2.7, about 2.8, about 2.9, about 3.0, about 3.1, about 3.2, about 3.3 about 3.4, about 3.5, about 3.6, about 3.7, about 3.8, or about 3.9 wt.%.

[0076] In this embodiment, Tables 5 and 6 show the flexural modulus (flex mod) in (1% Secant) in megapascals (MPa) of the baseline copolymer (e.g., 'Ref. Mat. 1 – Ref. Mat. 4'). The flex mod values may be between 350 and 775 MPa. For example, the flex mod values may be between 375 MPa to 750 MPa, 400 MPa to 725 MPa, 425 MPa to 700 MPa, 450 MPa to 675 MPa,

475 MPa to 650 MPa, 500 MPa to 625 MPa, 525 MPa to 600 MPa, 550 MPa to 575 MPa. In some embodiments, the flexural modulus is about 350 MPa, about 360, about 380, about 400, about 420, about 460, about 480, about 500, about 520, about 540, about 560, about 580, about 600, about 620, about 640, about 660, about 680, about 700, about 720, about 740, or about 760 MPa. Further, Tables 5 and 6 show the Young's modulus in megapascals (MPa) of the baseline copolymer (e.g., 'Ref. Mat. 1 – Ref. Mat. 4'). The Young's modulus values may be between 425 MPa and 1125 MPa. For example, the Young's modulus values may be between 450 MPa to 1100 MPa, 475 MPa to 1075 MPa, 500 MPa to 1050 MPa, 525 MPa to 1025 MPa, 550 MPa to 1000 MPa, 575 MPa to 975 MPa, 600 MPa to 950 MPa, 625 MPa to 925 MPa, 650 MPa to 900 MPa, 675 MPa to 875 MPa, 700 MPa to 850 MPa, 725 MPa to 825 MPa, 750 MPa to 800 MPa. In some embodiments, the Young's modulus is about 425 MPa, about 475, about 525, about 575, about 625, about 675, about 725, about 775, about 825, about 875, about 925, about 975, about 1025, or about 1075 MPa.

[0077] Further still, Tables 5 and 6 further show the strain at break in percent (%) of the baseline copolymer (e.g., 'Ref. Mat. 1 – Ref. Mat. 4'). The strain at break values may be between 500% to 800%. For example, the strain at break values may be about 500%, about 525, about 550, about 575, about 600, about 625, about 650, about 675, about 700, about 725, about 750, about 775, or about 800%. Tables 5 and 6 also show the strength at break in megapascals (MPa) of the baseline copolymer (e.g., 'Ref. Mat. 1 – Ref. Mat. 4'). The strength at break values may be between 20 MPa and 35 MPa. For example, the strength at break values may range between 21 MPa to 34 MPa, 22 MPa to 33 MPa, 23 MPa to 32 MPa, about 24 MPa to 31 MPa, about 25 MPa to 30 MPa, about 26 to 29, or about 27 to 28 MPa. In some embodiments, the strength at break value is about 20.5 MPa, about 21.5, about 22.5, about 23.5, about 24.5, about 25.5, about 26.5, about 27.5, about 28.5, about 29.5, about 30.5, about 31.5, about 32.5, about 33.5, or about 34.5 MPa.

[0078] In this embodiment, Tables 5 and 6 also show the strain at yield in percent (%) of the baseline copolymer (e.g., 'Ref. Mat. 1 – Ref. Mat. 4'). The strain at yield values may be between 10% and 20%. For example, the strain at yield values may range between 11% to 19%, 12% to 18%, 13% to 17%, or 14% to 16%. In some embodiments, the strain at yield value is about 10.2%, about 11.2, about 12.2, about 13.2, about 14.2, about 15.2, about 16.2, about 17.2, about 18.2, or about 19.2%. Tables 5 and 6 also show the strength at yield in megapascals (MPa) of the baseline copolymer (e.g., 'Ref. Mat. 1 – Ref. Mat. 4'). The strength at yield values may be between 12 MPa and 28 MPa. For example, the strength at yield values may range between 13 MPa to 27

MPa, 14 MPa to 26 MPa, 15 MPa to 25 MPa, 16 MPa to 24 MPa, 17 MPa to 23 MPa, 18 MPa to 22 MPa, or 19 MPa to 21 MPa. In some embodiments, the strength at yield value is about 12.6 MPa, about 13.6, about 14.6, about 15.6, about 16.6, about 17.6, about 18.6, about 19.6, about 20.6, about 21.6, about 22.6, about 23.6, about 24.6, about 25.6, about 26.6, or about 27.6 MPa.

5 **[0079]** Tables 5 and 6 also show the crystallization temperature (T_c) peak ($^{\circ}\text{C}$) of the baseline copolymer (e.g., 'Ref. Mat. 1 – Ref. Mat. 4'). The T_c peak values may be between 60°C to 120°C . For example, the T_c peak values may range between 65°C to 115°C , 70°C to 110°C , 75°C to 105°C , 80°C to 100°C , 85°C to 95°C , about 60°C , about 62, about 64, about 66, about 68, about 70, about 74, about 76, about 78, about 80, about 82, about 84, about 86, about 88, about 90, about
10 92, about 94, about 96, about 98, about 100, about 102, about 104, about 106, about 108, about 110, about 112, about 114, about 116, about 118, or about 120°C . Further, Tables 5 and 6 show the melting temperature (T_m) peak ($^{\circ}\text{C}$) of the baseline copolymer (e.g., 'Ref. Mat. 1 – Ref. Mat. 4'). The T_m peak values may be between 75°C to 150°C . For example, the T_m peak values may range between 80°C to 145°C , 85°C to 140°C , 90°C to 135°C , 95°C to 130°C , 100°C to 125°C ,
15 105°C to 120°C , or 110°C to 115°C . In some embodiments, the T_m peak is at about 76°C , about 78, about 80, about 82, about 84, about 86, about 88, about 90, about 92, about 94, about 96, about 98, about 100, about 102, about 104, about 106, about 108, about 110, about 112, about 114, about 116, about 118, about 120, about 122, about 124, about 126, about 128, about 130, about 132, about 134, about 136, about 138, about 140, about 142, about 144, about 146, about 148, or about
20 150°C .

[0080] Further, Table 5 shows the melt flow rate (MFR) in grams/10 minutes (g/10min) of the EP composition 22 (e.g., 'Ex. Mat. 18 – Ex. Mat. 20') in accordance with the present disclosure. The MFR values may be between 6.0 g/10min and 9.0 g/10min. For example, the MFR for the EM RCP family may be about 6.0 g/10min, about 6.5, about 7.0, about 7.5, about 8.0, about 8.5,
25 or about 9.0 g/10min.

[0081] In general, Table 5 also shows the C2 weight percent (wt.%) of the EP composition 22 (e.g., 'Ex. Mat. 18 – Ex. Mat. 20') acquired with FTIR. In general, the wt.% amounts may be between 2.5 to 5.0 wt.%. For example, the wt.% for the EM RCP family may be about 2.5 wt.%, about 2.6, about 2.7, about 2.8, about 2.9, about 3.0, about 3.1, about 3.2, about 3.3 about 3.4,
30 about 3.5, about 3.6, about 3.7, about 3.8, about 3.9, about 4.0, about 4.1, about 4.2, about 4.3, about 4.4, about 4.5, about 4.6, about 4.7, about 4.8, about 4.9, or about 5.0 wt.%.

[0082] In this embodiment, Table 5 shows the flexural modulus (flex mod) in (1% Secant) in megapascals (MPa) of the EP composition 22 (e.g., 'Ex. Mat. 18 – Ex. Mat. 20'). The flex mod values may be between 450 MPa and 750 MPa. For example, the flex mod values may be between 475 MPa to 725 MPa, 500 MPa to 700 MPa, 525 MPa to 675 MPa, 550 MPa to 650 MPa, or 575 MPa to 625 MPa. In some embodiments, the flex mod value is about 460 MPa, about 480, about 500, about 520, about 540, about 560, about 580, about 600, about 620, about 640, about 660, about 680, about 700, about 720, or about 740 MPa. Further, Table 5 shows the Young's modulus in megapascals (MPa) of the EP composition 22 (e.g., 'Ex. Mat. 18 – Ex. Mat. 20'). The Young's modulus values may be between 625 MPa to 1000 MPa. For example, the Young's modulus values may be between 650 MPa to 975 MPa, 675 MPa to 950 MPa, 700 MPa to 925 MPa, 725 MPa to 900 MPa, 750 MPa to 875 MPa, 775 MPa to 850 MPa, or 800 MPa to 825 MPa. In some embodiments, the Young's modulus value is about 630 MPa, about 660, about 690, about 710, about 740, about 770, about 800, about 830, about 860, about 890, about 910, about 940, about 970, or about 1000 MPa.

[0083] Further still, Table 5 further shows the strain at break in percent (%) of the EP composition 22 (e.g., 'Ex. Mat. 18 – Ex. Mat. 20'). The strain at break values may be between 750% to 800%. For example, the strain at break values may be about 750%, about 755, about 760, about 765, about 770, about 775, about 780, about 785, about 790, about 795, or about 800%. Table 5 also shows the strength at break in megapascals (MPa) of the EP composition 22 (e.g., 'Ex. Mat. 18 – Ex. Mat. 20'). The strength at break values may be between 30 MPa and 35 MPa. For example, the strength at break values may be about 30 MPa, about 31, about 32, about 33, about 34, or about 35 MPa.

[0084] In this embodiment, Table 5 also shows the strain at yield in percent (%) of in of the EP composition 22 (e.g., 'Ex. Mat. 18 – Ex. Mat. 20'). The strain at yield values may be between 10% and 15%. For example, the strain at yield values may be about 10.2%, about 11.2, about 12.2, about 13.2, or about 14.2%. Table 5 also shows the strength at yield in megapascals (MPa) of the EP composition 22 (e.g., 'Ex. Mat. 18 – Ex. Mat. 20'). The strength at yield values may be between 15 MPa and 25 MPa. For example, the strength at yield values may range between 16 MPa to 24 MPa, 17 MPa to 23 MPa, 18 MPa to 22 MPa, 19 MPa to 21 MPa, about 15.6 MPa, about 16.6, about 17.6, about 18.6, about 19.6, about 20.6, about 21.6, about 22.6, about 23.6, or about 24.6 MPa. Table 5 also shows the crystallization temperature (T_c) peak (°C) of the EP composition 22 (e.g., 'Ex. Mat. 18 – Ex. Mat. 20'). The T_c peak values may be between 70°C to 100°C. For example, the T_c peak values may be about 70°C, about 74, about 76, about 78, about 80, about 82,

about 84, about 86, about 88, about 90, about 92, about 94, about 96, about 98, or about 100°C. Further, Table 5 shows the melting temperature (T_m) peak (°C) of the EP composition 22 (e.g., 'Ex. Mat. 18 – Ex. Mat. 20'). The T_m peak values may be between 110°C to 125°C. For example, the T_m peak values may be about 112°C, about 114, about 116, about 118, about 120, about 122, or about 124 °C.

[0085] Further, Table 6 demonstrates that Ex. Mat. 7 – Ex. Mat. 16 EP composition 22 display T_m values greater than the baseline composition Ref. Mat. 1 due to increased crystallinity, which is advantageous as it may be used in applications where high T_m is necessary. In general, the MFR may be measured using ASTM-D1238. The T_c and T_m peaks were determined using scanning calorimetry (DSC) data that was measured at heating/cooling rate of 10 °C/min. The data is represented based on the mean value from 5 measurements.

[0086] Accordingly, Tables 5 and 6 show properties of EP composition 22 and baseline copolymers such as melt flow rate, amount of C2, mechanical properties (e.g, Young's modulus and flex mod), strain properties, strength properties, crystallization temperature, and melting temperature. In general, Tables 5 and 6 demonstrate that the EP composition 22 resins exhibit an MFR between 3-12 g/10 min, flex mod 1% secant > 600 MPa, and increasing toughness (strength at break) between 27-35 MPa.

[0087] As described in Table 1, this disclosure also describes polymers with specific crystallinity properties. It is presently recognized that r_1r_2 is used as an indicator of polymer blockiness or monomer clustering in a copolymer. Ethylene insertions function as defects during crystallization and random incorporation thereof leads to more polypropylene breaks and shorter polypropylene crystallite runs. This results in a decrease in the crystallinity of the EP resin, which leads to low mechanical properties (e.g., flexural modulus 1% secant limited to about 500 MPa) and low melting temperatures (e.g., melting temperature limited to about 110°C). Thus, polymer blockiness can be controlled by decreasing the relative concentration of ethylene in the reactor to create longer runs of propylene between ethylene segments. The more segmented monomer sequencing allows for improved polymer folding resulting in higher polymer crystallinity and melting temperatures.

[0088] FIG. 2 is a graph illustrating 1% secant modulus of flexural strength in MPa (y-axis) versus melt temperature in °C (x-axis) of different polymers and RCPs including RCPs made in accordance with the method of FIG. 1. In particular, graph 40 shows the 1% secant modulus of flexural strength versus temperature for a first symbol 48 corresponding to the catalyst 16, a

second symbol 50 corresponding to baseline copolymers, a third symbol 52 corresponding to terpolymers, and a fourth symbol 54 corresponding to polypropylene produced using a Zeigler Natta (ZN) catalyst. As shown in FIG. 2, there are three boxes within the graph that represent different regions, represented by box 42, box 44, and box 46, respectively, that correspond to certain ranges of 1% secant modulus and melt temperature properties. Box 42 refers to a region where RCPs may exhibit flex mod 1% sec values about 200 to about 700 MPa, and melting temperatures may range between about 100°C to about 120°C. Box 46 refers to a region where RCPs may exhibit flex mod 1% sec values about 700 MPa to about 900 MPa, and melting temperatures may range between about 120°C to about 130°C. Box 44 refers to a region where RCPs may exhibit flex mod 1% sec values about 700 to about 800 MPa, and melting temperatures may range between about 135°C to about 150°C. Although the range of box 46 in FIG. 2 is shown as ending at about 900 MPa, the flex mod 1% sec values may exceed 900 (e.g., about 1000 MPa as shown in Table 6, with respect to Ex. Mat. 14, Ex. Mat. 15, and Ex. Mat. 16). As shown in FIG. 2, a majority of the compositions corresponding to the first symbol 48 reside within box 46, which represents a region that has been previously unobtainable by previously synthesized RCPs. Compared to the compositions corresponding to the second symbol 50, the third symbol 52, and the fourth symbol 54, the compositions corresponding to the first symbol 48 provide access to a low-melt, high stiffness regime in box 46.

[0089] In general, the compositions within boxes 42 and 44 represent regions where RCPs exhibit flex mod strength and melting temperatures obtainable with techniques understood by one of ordinary skill in the art, respectively. However, the techniques used to produce the compositions corresponding to the second symbol 50, the third symbol 52, and the fourth symbol 54, may not produce compositions within box 46. Advantageously, it is presently recognized that producing polymer compositions in accordance with the disclosed techniques may provide a broader range of tunability with respect to mechanical properties and melt temperature. This is demonstrated by the compositions corresponding to the first symbol 48 that are within the box 42 and the box 46.

[0090] FIG. 3 is a graph illustrating crystallization rates $(1/t_{1/2})^{s-1}$ versus temperature in °C of RCPs made with varying C2 amounts in accordance with the method of FIG. 1. In general, the measurements were made using isothermal scanning calorimetry (DSC) data that was measured at heating/cooling rate of 10 °C/min from a range of -50°C to 200°C. Isothermal DSC (FIG 3) was performed by the method described in Carlos R. López-Barrón, John R. Hagadorn, and Joseph A. Throckmorton *Macromolecules* **2020** 53 (17), 7439-7449. DOI: 10.1021/acs.macromol.0c01282. In particular, graph 60 shows rate of crystallization of RCPs versus temperature for a first trace

62 corresponding to an EP composition 22 with approximately 4% C₂ and a melt flow rate (MFR) of 12, a second trace 64 corresponding to baseline copolymer with approximately 3.8% C₂ and an MFR of 8.4, and a third trace 66 corresponding to an EP composition 22 with approximately 6.3% C₂ and an MFR of 41. As shown in FIG. 3, trace 62 has a faster crystallization rate than trace 64 at comparable C₂ amounts. However, trace 66 exhibits a crystallization rate similar to trace 64 even though trace 66 was synthesized with a greater amount of C₂.

[0091] FIG. 4 is a graph illustrating expansion ratio versus temperature in °C of different RCPs made in accordance with the method of FIG. 1. In general, the techniques for measuring the expansion ratios may be measured using ASTM D1622. Samples were foamed using a batch foaming apparatus described in Mu Sung Kweon et. al. *Polymers* **2022** 14 (1), 44. DOI: 10.3390/polym14010044. In particular, graph 80 shows the expansion ratio profiles of different RCPs versus temperature for a first trace 82 corresponding to Ex. Mat. 18, a second trace 84 corresponding to Ex. Mat. 19, a third trace 86 corresponding to Ex. Mat. 20, a fourth trace 88 corresponding to Ref. Mat. 4, and a fifth trace 90 corresponding to a baseline copolymer, Ref. Mat. 3. As shown in FIG. 4, compared to baseline copolymers (e.g., corresponding to traces 88 and 90), EP composition 22 polymers (e.g., corresponding to traces 82, 84, and 86) exhibit higher stiffness and foamed at a temperature that is approximately 10 or 20°C lower than trace 88 and trace 90, respectively. Further, traces 82, 84, and 86 includes a peak expansion ratio that occurs at less than approximately 95°C, less than approximately 94°C, less than approximately 93°C, less than approximately 92°C, less than approximately 91°C, less than approximately 90°C. It is noted that trace 82 foamed 10 degrees lower than trace 84 and 86. Without wishing to be bound by theory, it is believed that an increase in C₂ amount can decrease the stiffness and may negatively impact foam quality compared to traces 84 and 86.

[0092] FIG. 5 is a graph illustrating the log (e.g., natural log) of flexural modulus 1% secant (y-axis) versus C₂ content in weight percent (wt.%) (x-axis) in accordance with the method 10 of FIG. 1. In particular, graph 100 shows the log (flex mod 1% secant) versus C₂ content of resins exhibiting different r_{1r2} values (e.g., between 1.5 and 5.0). Line 102 generally illustrates a threshold range that indicates different flex mod values for a particular C₂ content based on the r_{1r2} value. Put differently, when the resin 24 and/or EP composition 22 has a first r_{1r2} value that exceeds an r_{1r2} threshold (e.g., 3.1, 3.2, 3.3, 3.4, 3.5, 3.6, 3.7, or greater than 3.7) or is within a first r_{1r2} threshold range (e.g., between 3.7 and 5.0, between 3.1 and 4.5, between 3.3 and 5.5, greater than or equal to 3.3, greater than or equal to 3.4, greater than or equal to 3.5), the resin 24 and/or EP composition 22 will have a first flex mod value (e.g., corresponding to a flex mod value

above or along the line 102). Similarly, when the resin 24 and/or EP composition 22 has a second r_{1r2} value that is less than the r_{1r2} threshold or is outside of the first r_{1r2} threshold range, the resin 24 and/or EP composition 22 will have a second flex mod value (e.g., corresponding to a flex mod value below the line 102).

5 [0093] More specifically, as shown in FIG. 5, there is a box within the graph (box 104) that corresponds to a certain range of log (flex mod 1% secant) and C2 content properties. Box 104 refers to a region where resins may exhibit log (flex mod 1% secant) values about 6.55 MPa and about 6.61 MPa, and C2 content wt.% may range between 3.1 wt.% and 4.3 wt.%. The region above line 102 contains resins that exhibit larger r_{1r2} values, which is due to long propylene blocks, and this contributes significantly to polymer crystallinity in the form of log (flex mod 1% secant).
10 In other words, polymers with r_{1r2} values between 3.7 and 5.0 exhibit higher crystallinity, as indicated by log (flex mod 1% secant), due to incorporation of long propylene runs in between rapid, clustered, ethylene sequences, leading to blockier behavior than what has been previously observed. Importantly, graph 100 demonstrates that besides C2 content, polymer blockiness also contributes to polymer crystallinity properties. In an embodiment, the region below line 102 contains resins that exhibit smaller r_{1r2} values (between 1.9 and 3.7), which is due to short propylene blocks, and this contributes significantly to polymer crystallinity in the form of log (flex mod 1% secant). In other words, polymers with r_{1r2} values between 1.9 and 3.7 demonstrate lower crystallinity, as indicated by log (flex mod 1% secant), due to incorporation of short propylene runs in between rapid, clustered, ethylene sequences, leading to less blocky behavior. In general, this region demonstrates that increasing C2 content and lower r_{1r2} values reduce polymer crystallinity properties relative to the polymers that lie in the region above line 102.
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[0094] Further, graph 100 contains box 104. Box 104 refers to a region where resins may exhibit log (flex mod 1% secant) values about 6.55 MPa and about 6.61 MPa, and C2 content wt.% may range between 3.1 wt.% and 4.3 wt.%. The polymers in box 104 exhibit roughly similar mechanical properties yet vary in C2 content and r_{1r2} values, as indicated by the box traversing line 104, which is the division between polymers exhibiting large and small r_{1r2} values. This further indicates that the increase in polymer blockiness demonstrated by these resins is significant enough to offset the decrease in crystallinity that occurs from an increase in ethylene defects.
25 30 Advantageously, it is presently recognized that producing polymer compositions in accordance with the disclosed techniques may provide a broader range of tunability with respect to mechanical properties, melt temperature, polymer crystallinity, and C2 content.

[0095] FIG. 6 is a graph illustrating the natural log of flexural modulus 1% secant (y-axis) versus C2 content in weight percent (wt.%) (x-axis) in accordance with the method of FIG. 1. In particular, graph 110 shows the log (flex mod 1% secant) versus C2 content of resins from FIG. 5 exhibiting different r_{1r2} values. The resins are separated into three distinct groups by their r_{1r2} values and are fitted to 3 different lines, as denoted by line 112 with circle symbols, line 114 with square symbols, and line 116 with triangle symbols. Line 112 with circle symbols represents resins that exhibit r_{1r2} values greater than about 4. Line 114 with square symbols represents resins that exhibit r_{1r2} values between approximately 2.4 and approximately 4.0. Line 116 with triangle symbols represents resins that exhibit r_{1r2} values less than about 2.4.

[0096] Line 112, line 114, and line 116 can generally be represented using the function below:

$$y = m * C2 + (b + B(r_{1r2})) \quad (1)$$

where y is the property (e.g., log of flex mod), m is the slope, $C2$ is the C2 content, b is a constant related to the y-intercept, and B is related to the blockiness level. In general, B varies based on whether the r_{1r2} exceeds one or more r_{1r2} thresholds. For example, if r_{1r2} is less than a first threshold, B is a first value. If r_{1r2} is greater than the first threshold and less than a second threshold, then B is a second value different than the first value. If r_{1r2} is greater than the second threshold, then B is a third value that is different than the second value and/or the first value. A specific, non-limiting example of the function representing line 112, line 114, and line 116 is shown below:

$$y = 7.41 + -0.217 \times C2 + Match(Blockiness Level) \quad (2)$$

where the blockiness level is: "High" = 0.111; "Mid" = 0.00857; "Low" = -0.119. The linear regression model describes that C2 content and blockiness can be tuned accordingly to produce a resin with a specific crystallinity and melting temperature. Producing polymer compositions in accordance with the disclosed techniques provides advantages such as allowing for a broader range of tunability with respect to mechanical properties, melt temperature, polymer crystallinity, and C2 content.

[0097] As shown in FIG. 6, there is a box within the graph (box 118) that corresponds to a certain range of log (flex mod 1% secant) and C2 content properties. Box 118 refers to a region where resins may exhibit log (flex mod 1% secant) values between approximately 6.35 MPa and approximately 6.65 MPa, and C2 content wt.% may range between approximately 4.2 wt.% and approximately 4.4 wt.%. The resins in box 118 exhibit roughly similar C2 content yet vary

significantly in their polymer crystallinity. It is noted that the change in polymer crystallinity occurs independent of C2 content. Instead, the change in log (flex modulus 1% secant) is attributed to the difference in polymer blockiness. As denoted by line 118 in box 118, resins with high r_{1r2} values (greater than 4) exhibit high log (flex modulus 1% secant). This is attributed to
5 incorporation of long propylene units in between rapid, clustered ethylene sequences. The longer propylene runs create polymer blockiness, leading to high r_{1r2} values. However, line 116 in box 118 exhibits low r_{1r2} values (e.g., less than 2.4), and as a result, lower polymer crystallinity. This is attributed to incorporation of short propylene units, leading to less polymer blockiness and a low r_{1r2} value. In general, it is presently recognized that producing polymer compositions in
10 accordance with the disclosed techniques may provide a broader range of tunability with respect to mechanical properties, melt temperature, polymer crystallinity, and C2 content.

[0098] FIG. 7 is a graph illustrating the measured natural log of flexural modulus 1% secant (y-axis) vs. the predicted natural log of flexural modulus 1% secant (x-axis). In particular, graph 120 shows a scatter plot comprising the resins from FIG. 6 fitted to a linear regression model 122.
15 It should be noted that the linear regression model 122 is meant to be non-limiting and other models (e.g., lines, functions, equations) may be used.

[0099] In FIG. 7, the linear regression model (122) is plotted with respect to the null hypothesis, which is represented by 124. The linear regression model 122 also has confidence bands, as denoted by 126. As shown in FIG. 7, there are two boxes within the graph that represent different
20 regions, represented by box 128 and box 130 respectively, that correspond to resins within certain ranges of 1% secant modulus and r_{1r2} properties. It is noted that the data in graph 120 is in agreement with the linear regression model 122 and rejects the null hypothesis 124, with a $p < 0.0001$. The quality of the fit of the linear regression model 122 to the scatter plot is assessed by the R^2 value, which is 0.98749. The root-mean square error (RMSE) is 0.0339, which indicates
25 the data fits the linear regression model 122 has little error and can predict data with precision. Further, the confidence bands are narrow, indicating the linear regression model 122 has a good fit to the data.

[00100] The data points represented by circles, squares, and triangles are identical to the data points observed in FIG. 6. Circle symbols represent resins that exhibit r_{1r2} values greater than
30 about 4. Square symbols represent resins that exhibit r_{1r2} values between approximately 2.4 and approximately 4.0. Triangle symbols represent resins that exhibit r_{1r2} values less than about 2.4. Importantly, FIG. 7 shows box 128 contains resins that primarily exhibit r_{1r2} values between

approximately 2.4 and approximately 5.0 and log (flex mod 1% secant) measured (e.g., 'actual') vs. predicted between approximately 6.55 and approximately 6.75. However, box 130 contains resins that primarily exhibit r_1r_2 values between approximately 1.9 and approximately 2.4 and log (flex mod 1% secant) measured vs. predicted between approximately 6.05 and approximately 6.35. To this end, it is noted that polymer crystallinity (log (flex mod 1% secant)) increases with r_1r_2 values, while accounting for the amount of defects from ethylene insertions as the driving parameter. Box 128 provides access to resins that exhibit r_1r_2 values and polymer crystallinity properties that were previously unachievable. Advantageously, it is presently recognized that producing polymer compositions in accordance with the disclosed techniques may provide a broader range of tunability with respect to mechanical properties, melt temperature, polymer crystallinity, and C2 content.

[00101] FIGS. 8 and 9 show specific, non-limiting examples of size properties (molecular mass distribution (MMD) and composition properties (e.g., ethylene content (C₂%) and long chain branching (LCB)) of a copolymer (e.g., the resin 24). For example, FIG. 8 is a graph illustrating size properties of the resin 24 corresponding to Ex. Mat. 18 described with respect to Table 4. As shown, the graph 140 includes a first trace 142 that corresponds to the MMD as measured using infrared spectroscopy (IR) techniques. The graph 140 also includes a second trace 144 that corresponds to the MMD as measured using light scattering (LS) techniques. The graph 140 also includes a third trace 146 that corresponds to the MMD as measured using intrinsic viscosity (IV) techniques. Further, the graph 140 includes a fourth trace 148 that corresponds to a polymer reference. Even further, the graph 140 includes a fifth trace 150 that corresponds to LCB of the resin 24. Further still, the graph 140 includes a sixth trace 152 that corresponds to the C₂% of the resin 24. The sixth trace 152 has a non-zero slope (e.g., a linear, non-zero slope) that indicates that the resin 24 has heterogeneous composition. As shown, the C₂% of the resin 24 corresponding to Ex. Mat. 18 varies between approximately 5% and 10%. Accordingly, it is presently recognized that adjusting the r_1r_2 value may also control the heterogeneity of the resin 24 and/or EP composition 22.

[00102] FIG. 9 is a graph 160 illustrating size properties of the resin 24 corresponding to Ex. Mat. 16 described with respect to Table 4. As shown, the graph 160 includes a first trace 162 that corresponds to the MMD as measured using infrared spectroscopy (IR) techniques. The graph 160 also includes a second trace 164 that corresponds to the MMD as measured using light scattering (LS) techniques. The graph 160 also includes a third trace 166 that corresponds to the MMD as measured using intrinsic viscosity (IV) techniques. Further, the graph 160 includes a

fourth trace 168 that corresponds to a polymer reference. Even further, the graph 160 includes a fifth trace 170 that corresponds to LCB of the resin 24. Further still, the graph 160 includes a sixth trace 172 that corresponds to the C₂% of the resin 24. The sixth trace 162 has a slope that is approximately zero, which indicates that the resin 24 has homogeneous (uniform) composition. As shown, the C₂% of the resin 24 corresponding to Ex. Mat. 16 is approximately 2.5% with a standard deviation that is less than 15%, less than 10%, or less than 5%.

[00103] As such, the disclosed techniques may be used to generate EP compositions 22 and/or resins 24 that are heterogeneous or homogeneous. The heterogeneous compositions may have a C₂% maximum that is more than 20%, more than 25%, more than 30%, more than 50%, or more than 100% of the C₂% minimum.

[00104] Accordingly, the present disclosure is directed to a polymer resin produced from a mixture including ethylene monomers and polypropylene monomers. The melt temperature of the polymeric resin is less than approximately 140°C. The polymeric resin includes a flexural modulus between approximately 600 MPa and approximately 1000 MPa. In another embodiment, a polymer foam includes a random copolymer, wherein a random copolymer includes a mixture of ethylene and propylene monomers. The random copolymers foam in an operational window at approximately 100 °C or less. It is presently recognized that the polymer resins described herein significantly different properties than baseline resins, making these resins particularly advantageous for expanded bead foam applications. Technical aspects of the disclosure include producing polymer resins having decreased melt temperature and improved crystallinity, thereby providing improve processability with respect to certain applications, such as expanded bead foam applications.

[00105] This written description uses embodiments/examples to disclose the invention, including the best mode, and also to enable any person skilled in the art to practice the invention, including making and using any devices or systems and performing any incorporated methods. The patentable scope of the invention is defined by the claims, and may include other embodiments/examples that occur to those skilled in the art. Such other embodiments/examples are intended to be within the scope of the claims if they have structural elements that do not differ from the literal language of the claims, or if they include equivalent structural elements with insubstantial differences from the literal language of the claims. Many alterations, modifications, and variations will be apparent to those skilled in the art in light of the foregoing description without departing from the spirit or scope of the present disclosure and that when numerical lower

limits and numerical upper limits are listed herein, ranges from any lower limit to any upper limit are contemplated.

CLAIMS:

1. A propylene-based copolymer produced from a mixture comprising ethylene monomers and propylene monomers, wherein the propylene-based copolymer comprises:
 - 5 a flexural modulus between approximately 400 MPa and approximately 1100 MPa;
 - a molecular weight of about 200,000 g/mol to 800,000 g/mol;
 - a r_1r_2 reactivity ratio greater than or equal to 2.0; and
 - an ethylene content greater than approximately 2.5 weight percent (wt.%).
- 10 2. The propylene-based copolymer of claim 1, wherein the r_1r_2 reactivity ratio of the propylene-based copolymer is greater than or equal to 3.0.
3. The propylene-based copolymer of claim 1, wherein the r_1r_2 reactivity ratio of the propylene-based copolymer is greater than or equal to 4.0.
- 15 4. The propylene-based copolymer of claim 1, wherein a melt temperature of the propylene-based copolymer is less than approximately 140°C.
5. The propylene-based copolymer of claim 1, comprising a triad tacticity index based on
20 PP that is greater than 80%.
6. The propylene-based copolymer of claim 1, wherein the propylene-based copolymer comprises regioselectivity defects between 0.01 and 1.2 mol%.
- 25 7. The propylene-based copolymer of claim 1, wherein wherein the propylene-based copolymer further comprises a PDI of 1.8 to 5 and M_z/M_w of 1.5 to 4.0, and wherein the comonomer of the propylene-based copolymer is distributed uniformly, orthogonally, or

conventionally generated by single or multiple reactors connected in series or parallel configuration.

8. A method, comprising:

5 providing an ethylene feedstock at a first flow rate;

providing a propylene feedstock at a second flow rate, wherein a ratio (C_2/C_3) of the first flow rate to the second flow rate is less than or equal to approximately 0.06; and

generating an ethylene-propylene composition by contacting the propylene feedstock and the ethylene feedstock in the presence of a catalyst.

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9. The method of claim 8, wherein a ratio ($[C_2]/[M]$) of an amount of ethylene monomer and a sum of an amount of ethylene monomers and propylene monomers in a reactor is between less than or equal to approximately 0.025.

15 10. The method of claim 8, wherein a r_1r_2 reactivity ratio of the ethylene-propylene composition is greater than or equal to 2.0.

11. The method of claim 8, wherein a r_1r_2 reactivity ratio of the resin is greater than or equal to 4.0.

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12. The method of claim 8, wherein a ratio of the first flow rate to the second flow rate is between 0.005 kg/kg and 0.055 kg/kg.

25 13. The method of claim 8, wherein a propylene-propylene-propylene [PPP] mole fraction of the ethylene-propylene composition is between 0.8 to 0.9.

14. The method of claim 8, comprising a triad tacticity index based on PP and EP that is greater than 80%.

15. The method of claim 8, comprising contacting the propylene feedstock and the ethylene feedstock in the presence of the catalyst at a temperature between approximately 70°C and approximately 190°C.

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16. A method, comprising:

providing an ethylene feedstock at a first flow rate;

providing a propylene feedstock at a second flow rate, wherein the ratio ($[C2]/[M]$) of an amount of ethylene monomer and a sum of an amount of ethylene monomers and propylene monomers in a reactor is between less than or equal to approximately 0.025; and

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generating an ethylene-propylene composition by contacting the propylene feedstock and the ethylene feedstock in the presence of a catalyst.

17. The method of claim 16, wherein the ethylene-propylene composition comprises a triad tacticity index based on PP that is greater than 90%.

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18. The method of claim 16, wherein the ethylene-propylene composition has a melt temperature between approximately 70°C to approximately 130°C.

19. The method of claim 16, wherein the ethylene-propylene composition comprises ethylene content greater than or equal to 2.5 weight percent (wt.%).

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20. The method of claim 16, wherein a propylene-propylene-propylene [PPP] mole fraction of the ethylene-propylene composition is approximately 0.86.

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