

**ENCAPSULATED FLAME RETARDANT COMPOSITIONS, METHODS OF MAKING
ENCAPSULATED FLAME RETARDANT COMPOSITIONS, AND ARTICLES
INCLUDING THE ENCAPSULATED FLAME RETARDANT COMPOSITIONS**

BACKGROUND

[0001] Various commercial polymers from commodity to engineering plastics such as polyolefins, polystyrenes, polyesters and polyamides have been extensively used in many engineering applications due to their versatile properties. However, poor flame resistance can preclude their use in some applications. This is because most polymers has relatively low limiting oxygen index (LOI). Covalently bonded back-bone chains are decomposed and burned when polymers are exposed to fire. There are various types of fire-retardant materials that can impart fire-resistance properties to polymers. Among the many types of fire retardants, halogen compounds are widely applied for polyolefins due to their advantages such as cost-effectiveness, good processibility and efficient fire retardation. Brominated flame retardants (BrFRs) are primarily effective because of the acceptable range of the bond energy between aliphatic (or aromatic) carbon and bromine. The bond energy is neither too high nor low that they are decomposed and perform the function of neutralization to hydrogen or hydroxyl radicals generated by fire.

[0002] One common BrFR, brominated polystyrene (BPS), causes a drop of mechanical properties such as tensile strength, flexural strength, and impact strength in polyolefins into which it is incorporated. The fracture toughness value (critical energy release rate, G_{IC}) for polypropylene (PP) containing BrFRs shows substantial reductions up to 50% compared to neat PP under the impact condition. Generally, the drop in mechanical properties is caused by the weak interfacial strength between two different polymers in the blends. Wei et al. reported the use of a styrenic block copolymer to improve adhesion between PP and polyphenylene ether (Noryl) resulting in improved fracture toughness. Several simulation studies have shown that rubber-coated particles can improve fracture toughness of three-phase polymer composites when a rigid spherical particle has a rubber coating which exceeds a certain level of thickness. However, these modeling studies have limitations, including the assumption that each interface has perfect boundaries. In the case of hard polymeric particles, the particle size changes quite significantly depending on processing conditions. In addition, the adhesion of the interface also depends on the processing conditions, so the overall morphology varies simultaneously in ways that are not accounted for by standard models.

[0003] Despite advances in flame-retardant polymer research, there is still a scarcity of compositions that achieve good flame-retardant properties while maintaining high processability using existing equipment and producing articles having excellent mechanical properties. These needs and other needs are satisfied by the present disclosure.

SUMMARY

[0004] In accordance with the purpose(s) of the present disclosure, as embodied and broadly described herein, the disclosure, in one aspect, relates to flame-retardant plastic compositions including a polymeric component and a brominated flame retardant, wherein the brominated flame retardant is composed of one or more particles at least partially encapsulated by a thermoplastic toughener. In some aspects, the encapsulation can take the form of a core-shell structure, wherein the shell has an average thickness of from about 5 nm to about 10 μm . The thermoplastic toughener can be a thermoplastic elastomer such as, for example, a styrenic block copolymer (with or without a maleic anhydride graft), a thermoplastic polyurethane, a nitrile butadiene rubber, an acrylic elastomer, a copolyester elastomer, a thermoplastic polyether ester elastomer (TPEE), a thermoplastic amide ether elastomer (TAEE), a chlorinated rubber, an ionomer, a thermoplastic vulcanizate, a polyolefin elastomer or any combination thereof. In some aspects, the flame-retardant plastic compositions additionally include a filler and/or a compatibilizer such as, for example, a maleic anhydride grafted PP. Also, disclosed are methods for making the flame-retardant plastic compositions and articles made from the compositions.

[0005] Other systems, methods, features, and advantages of the present disclosure will be or become apparent to one with skill in the art upon examination of the following drawings and detailed description. It is intended that all such additional systems, methods, features, and advantages be included within this description, be within the scope of the present disclosure, and be protected by the accompanying claims. In addition, all optional and preferred features and modifications of the described embodiments are usable in all aspects of the disclosure taught herein. Furthermore, the individual features of the dependent claims, as well as all optional and preferred features and modifications of the described embodiments are combinable and interchangeable with one another.

BRIEF DESCRIPTION OF THE DRAWINGS

[0006] Many aspects of the present disclosure can be better understood with reference to the following drawings. The components in the drawings are not necessarily to scale,

emphasis instead being placed upon clearly illustrating the principles of the present disclosure. Moreover, in the drawings, like reference numerals designate corresponding parts throughout the several views.

[0007] FIG. 1A shows a schematic diagram describing single-notch three-point-bend (SN3PB) testing geometry. FIG. 1B shows a top and front view of SN3PB. FIG. 1C shows an optical microscopy (OM) image of the sharp crack. FIG. 1D shows top and front views of SN3PB test to get U_0 term. FIG. 1E shows an OM image of the cracked specimen.

[0008] FIG. 2A shows a side view of sharp crack generation for SN3PB and double-notch four-point-bend (DN4PB) specimens below the machined slots. FIG. 2B shows cross-sectional view of the fracture surface in SN3PB specimens after impact fractures.

[0009] FIG. 3A shows a schematic diagram describing DN4PB testing geometry. FIG. 3B shows a top view and FIG. 3C shows a front view of DN4PB. FIG. 3D shows a petrographic thin section in a glass slide and a transmitted light optical microscopy (TOM) image for polypropylene (PP) in mid-plane (plane strain region) of the specimen from an arrested crack.

[0010] FIGs. 4A-4D show TEM images for four systems: PP/BPS[L] (FIG. 4A), PP/BPS/SEBS[SD] (FIG. 4B), PP/BPS[S] (FIG. 4C), and PP/BPS/SEBS[CS] (FIG. 4D). The top left numbers in each image represent the average particle size of BPS in that image. Abbreviations: PP = polypropylene; BPS = brominated polystyrene; SEBS = styrene-ethylene-butylene-styrene; L = large particles and S = small particles (see Examples for size information); SD = separately dispersed particles; CS = core shell particles.

[0011] FIG. 5A shows surface energy vs surface coverage. FIG. 5B shows interfacial energy vs temperature. FIG. 5C shows spreading coefficient, $S_{BPS-SEBS}$ vs temperature. FIG. 5D shows spreading coefficient, $S_{SEBS-BPS}$ vs temperature. FIG. 5E shows morphology types and their satisfying conditions.

[0012] FIG. 6A shows Izod impact strength and FIG. 6B shows tensile strength for several model systems as described herein.

[0013] FIGs. 7A-7F show plots of energy (E) vs normalized area ($BD\phi$) for PP/BPS[L] (FIG. 7A), PP/BPS/SEBS[SD] (FIG. 7B), PP/BPS[S] (FIG. 7C), PP/BPS/SEBS[CS] (FIG. 7D), PP (FIG. 7E), and PP/SEBS (FIG. 7F).

[0014] FIGs. 8A-8B show TOM and POM, respectively, of PP/BPS[L]. FIGs. 8C-8D show TOM and POM, respectively, of PP/BPS/SEBS[SD] from arrested cracks after DN4PB.

[0015] FIGs. 9A-9B show TOM and polarized light optical microscopy (POM), respectively

of PP/BPS[S]. **FIGs. 9C-9D** show TOM and POM, respectively, of PP/BPS/SEBS[CS] from arrested cracks after DN4PB.

[0016] **FIG. 10** shows TEM observation for PP/BPS/SEBS[CS] from the arrested crack after DN4PB test.

[0017] **FIGs. 11A-11B** show TOM and POM, respectively, of PP. **FIGs. 11C-11D** show TOM and POM, respectively, of PP/SEBS from arrested cracks after DN4PB.

[0018] **FIG. 12** shows a schematic diagram for possible toughening mechanisms.

[0019] **FIGs. 13A-13C** show a double-notch four-point bending specimen (**FIG. 13A**) and toughening mechanism study via fracture surface analysis (**FIG. 13B**) and damage zone observation (**FIG. 13C**).

[0020] **FIG. 14** shows the effects of SEBS rubber and processing temperature on morphology.

[0021] **FIGs. 15A-15B** show TEM images of an 8phr/230 °C system.

[0022] **FIG. 16** shows complex viscosities as a function of angular frequency.

[0023] **FIG. 17** shows Cole-Cole plots of neat polymers and LLDPE/BPS/SEBS blend systems.

[0024] **FIG. 18** shows representative engineering stress-engineering strain plots.

[0025] **FIG. 19** shows notched Izod impact strength at -37 °C.

[0026] **FIGs. 20A-20D** show OM images of the crack tip damage zone under bright field (left) and crossed polars (right): (**FIGs. 20A-20B**) 8 phr/230 °C and (**FIGs. 20C-20D**) 8 phr/185 °C.

[0027] **FIGs. 21A-21D** show SEM analyses of fracture surfaces of (**FIG. 21A**) LLDPE; (**FIG. 21B**) 8 phr/185 °C; (**FIG. 21C**) and (**FIG. 21D**) 8 phr/230 °C.

[0028] **FIGs. 22A-22Z** show TEM images of experimental compositions. Red arrows indicate brominated flame retardants, while blue arrows indicate thermoplastic elastomers. Specific compositions are provided in Example 5.

[0029] Additional advantages of the invention will be set forth in part in the description which follows, and in part will be obvious from the description, or can be learned by practice of the invention. The advantages of the invention will be realized and attained by means of the elements and combinations particularly pointed out in the appended claims. It is to be understood that both the foregoing general description and the following detailed

description are exemplary and explanatory only and are not restrictive of the invention, as claimed.

DETAILED DESCRIPTION

[0030] The present disclosure provides for flame-retardant plastic compositions, methods of making flame-retardant plastic compositions, and articles including the flame-retardant plastic composition. The flame-retardant plastic composition of the present disclosure can be advantageous in that the fracture toughness can be improved. While not intending to be bound by theory, the toughening mechanism can include the promotion of crazing initiation/shear banding. Additional features of the present disclosure can be provided below and in the Examples.

[0031] In an aspect, the flame-retardant plastic composition can be used in articles such as molded parts for use in housing or connectors or circuit boards for electronics, various automotive uses such as parts in the engine compartment, seating, insulation and interior components, and residential uses such as insulation, carpeting, and wall coverings. In another aspect, the articles can be coverings for cables and/or wires. In yet another aspect the disclosed articles can be used in textiles and adhesives.

[0032] In an aspect, the flame-retardant plastic composition can include a polymeric component and a brominated flame retardant. The brominated flame retardant can be composed of one or more particles, where one or more particles can be at least partially encapsulated by a thermoplastic toughener. The flame-retardant plastic composition can include one or more particles that are not encapsulated by the thermoplastic toughener. The flame-retardant plastic composition can include particles that vary in the degree of encapsulation from entirely encapsulated to no encapsulation. Alternatively to or in addition to the above, one or more clusters including two or more particles can include varying degrees of encapsulation. As a result, aspects of present disclosure provide for flame-retardant plastic compositions that can be very complex in that individual particles can be encapsulated to some degree or fully, clusters of two or more particles that can be encapsulated to some degree or fully, individual particles that are not encapsulated, and clusters of particles that are not encapsulated. In an aspect, the weight percent of particles and/or clusters of particles that can be at least partially encapsulated can be about 1 to 100 weight percent, about 5 to 90 weight percent, about 15 to 75 weight percent, or 30 to 50 weight percent of the total weight of particles and/or clusters of particles.

[0033] In one aspect, the one or more particles of the brominated flame retardant can be found in one or more of the following forms: (i) a plurality of particles individually partially encapsulated by the thermoplastic toughener, (ii) a plurality of particles individually fully

encapsulated by the thermoplastic toughener, (iii) a plurality of clusters of two or more particles, wherein the individual clusters of the plurality are partially encapsulated as a group by the thermoplastic toughener, (iv) a plurality of clusters of two or more particles, wherein the individual clusters of the plurality are fully encapsulated as a group by the thermoplastic toughener, or (v) any combination thereof.

[0034] In any of these aspects, the one or more particles at least partially encapsulated by the thermoplastic toughener have a core-shell structure, where the thermoplastic toughener forms the shell or partial shell and the brominated flame retardant forms the core. In an aspect, the shell layer of the core-shell structure has an average thickness of from about 5 nm to about 10 μ m, from about 5 nm to about 1 μ m, from about 5 nm to about 200 nm, from about 100 nm to about 200 nm, or of about 5, 10, 15, 20, 25, 50, 100, 150, 200, 250, 300, 350, 400, 450, 500, 550, 600, 650, 700, 750, 800, 850, 900, 950, or about 1000 nm (1 μ m), or a combination of any of the foregoing values, or a range encompassing any of the foregoing values. In any of these aspects, a ratio of the average thickness of the shell layer to an average length in at least one dimension of a core layer of the core-shell structure is from about 0.05:1 to about 0.25:1, from about 0.05:1 to about 0.1:1, from about 0.1:1 to about 0.2:1, or is about 0.05:1, 0.1:1, 0.15:1, 0.2:1, or about 0.25:1, or a combination of any of the foregoing values, or a range encompassing any of the foregoing values.

[0035] In one aspect, and without wishing to be bound by theory, the thermoplastic toughener achieves good dispersion of brominated flame retardants in the polymeric component and can coat brominated flame retardant particles with sufficient thickness to transform the brominated flame retardants into toughening particles. The thermoplastic toughener may additionally act as a compatibilizer and is described further below. In one aspect, and without wishing to be bound by theory, the toughener acts as an interface between the brominated flame retardant and the polymeric component.

[0036] In one aspect, the polymeric component can be selected from polystyrene, low-density polyethylene (LDPE), linear low-density polyethylene (LLDPE), very-low-density polyethylene (VLDPE), ultra-low-density polyethylene (ULDPE), medium-density polyethylene (MDPE), polypropylene (PP), polymethylpentene (PMP), polybutene-1 (PB-1), ethylene-octene copolymer, stereo-block PP, olefin block copolymer, propylene-butane copolymer, polyisobutylene (PIB), poly(α -olefin), ethylene propylene rubber (EPR), ethylene propylene diene monomer rubber (EPDM rubber), high-density polyethylene (HDPE), ultra-high density polyethylene (UHDPE), a polyamide, a polyester, a styrenic polymer or copolymer, cross-linkable or cross-linked polyethylene (PEX or XLPE), or any combination thereof.

[0037] In some aspects, when the polymeric component is or includes a polyamide, the polyamide can be selected from nylon 6,6; nylon 6; nylon 6, 10; nylon 11; nylon 6,12; nylon 12; nylon 6,9; nylon 4,6; poly(m-phenylene isophthalamide); poly(p-phenylene terephthalamide); copoly(p-phenylene/d,4'-diphenyl ether terephthalamide); PA66/6, PA6T, PA9T, PA10T, PA4T, poly(m-xylene sebacamide), poly(m-xylene adipamide), a copolymer thereof, or any combination thereof. In another aspect, when the polymeric component is or includes a polyester, the polyester can be selected from polyethylene terephthalate (PET), polytrimethylene terephthalate (PTT), polybutylene terephthalate (PBT), poly(cyclohexylenedimethylene terephthalate) (PCT), polylactic acid (PLA), polycaprolactone (PCL), polyethylene terephthalate glycol (PETG), polycyclohexylenedimethylene terephthalate glycol (PCTG), or any combination thereof. In still another aspect, when the polymeric component is or includes a styrenic polymer or copolymer, the styrenic polymer or copolymer can be selected from poly(styrene-co-acrylonitrile) (SAN), poly(acrylonitrile-co-butadiene-styrene) (ABS), or any combination thereof. In one aspect, the polymeric component is polypropylene, polystyrene, linear low-density polyethylene (LLDPE), or ethylene-1-octene copolymer.

[0038] In another aspect, the brominated flame retardant can be selected from 1,2-bis(pentabromophenyl)ethane, brominated polystyrene, ethylene-bis-tetrabromophthalimide, decabromodiphenyl oxide, brominated polystyrene; poly(bromostyrene), polyvinyl bromide, polyvinylidene bromide, poly(2-bromoethyl methacrylate), poly(2,3-dibromopropyl methacrylate), poly(methyl-a-bromoacrylate), butadiene styrene brominated copolymer, or any combination thereof.

[0039] In an aspect, the thermoplastic toughener can be a thermoplastic elastomer such as, for example, a styrenic block copolymer, a thermoplastic polyurethane, a nitrile butadiene rubber, an acrylic elastomer, a copolyester elastomer, a thermoplastic polyether ester elastomer (TPEE), a thermoplastic amide ether elastomer (TAEE), a chlorinated rubber, an ionomer, a thermoplastic vulcanizate, or any combination thereof. In one aspect, when the thermoplastic toughener is or includes a nitrile butadiene rubber, the nitrile butadiene rubber can be a hydrogenated nitrile butadiene rubber. In another aspect, when the thermoplastic toughener is or includes a styrenic block copolymer, the styrenic block copolymer can be selected from a styrene-ethylene butylene-styrene block copolymer (SEBS), a maleic anhydride grafted SEBS block copolymer, a styrene-ethylene propylene-styrene block copolymer (SEPS), or any combination thereof. In one aspect, when the toughener is or includes SEBS, the SEBS has a styrene to ethylene and butylene ratio of from about 10:90 to about 70:30, from about 20:80 to about 50:50, from about 50:50 to about 70:30, or of about 10:90, 20:80, 30:70, 40:60, 50:50, 60:40, or about 70:30, or a

combination of any of the foregoing values, or a range encompassing any of the foregoing values. In another aspect, when the thermoplastic toughener is or includes a thermoplastic polyurethane, the thermoplastic polyurethane can be a polyester polyurethane, a polyether polyurethane, or any combination thereof. In still another aspect, when the thermoplastic toughener is or includes an acrylic elastomer, the acrylic elastomer can be ethylene acrylic terpolymer. In one aspect, when the thermoplastic toughener is or includes a chlorinated rubber, the chlorinated rubber can be polychloroprene, a chloro polyethylene copolymer, or any combination thereof. In one aspect, and without wishing to be bound by theory, unlike in the inventive compositions of the present application, some SEBS polymers do not encapsulate or partially encapsulate brominated flame retardants when mixed, and not all mixed systems including SEBS and brominated flame retardants can thus be said to satisfy the system as disclosed herein.

[0040] In any of these aspects, the flame-retardant plastic composition can further include a compatibilizer. In one aspect, the compatibilizer can be a maleic anhydride grafted polypropylene.

[0041] In one aspect, the flame retardant plastic composition can include from about 65% to about 85% by weight of the polymeric component, from about 65% to about 75% by weight of the polymeric component, from about 70% to about 80% by weight of the polymeric component, or about 65, 70, 75, 80, or about 85% by weight of the polymeric component, or a combination of any of the foregoing values, or a range encompassing any of the foregoing values. In another aspect, the flame-retardant plastic composition can include from about 5% to about 35% by weight of the brominated flame retardant, from about 15% to about 25% by weight of the brominated flame retardant, from about 20% to about 30% by weight of the brominated flame retardant, or about 5, 10, 15, 20, 25, 30, or about 35% by weight of the brominated flame retardant, or a combination of any of the foregoing values, or a range encompassing any of the foregoing values.

[0042] In some aspects, the flame-retardant plastic compositions disclosed herein can also include a synergist. In a further aspect, the synergist can be antimony trioxide (herein Sb_2O_3 or ATO) or another synergist. In another aspect, the flame-retardant compositions can include from about 1% to about 10%, about 1% to about 5%, about 5% to about 10%, or about 3% to about 7% by weight of Sb_2O_3 or other synergist, or about 1, 2, 3, 4, 5, 6, 7, 8, 9, or about 10% by weight Sb_2O_3 or other synergist, a combination of any of the foregoing values, or a range encompassing any of the foregoing values.

[0043] In still another aspect, the flame-retardant plastic composition can include from about 4% to about 8% by weight of the thermoplastic toughener, from about 4% to about

6% by weight of the thermoplastic toughener, from about 6% to about 8% by weight of the thermoplastic toughener, or about 4, 4.5, 5, 5.5, 6, 6.5, 7, 7.5, or about 8% by weight of the thermoplastic toughener, or a combination of any of the foregoing values, or a range encompassing any of the foregoing values. In still another aspect, the flame-retardant plastic composition can include from about 0% to about 2% by weight of the compatibilizer, from about 0.25 to about 0.5% by weight of the compatibilizer, from about 0.5% to about 1% by weight of the compatibilizer, or about 0, 0.25, 0.5, 0.75, 1, 1.25, 1.5, 1.75, or about 2% by weight of the compatibilizer, or a combination of any of the foregoing values, or a range encompassing any of the foregoing values. In any of these aspects, weight percent is based on the total weight of the polymeric component, the brominated flame retardant, the thermoplastic toughener, and, if present, the compatibilizer.

[0044] In another aspect, the flame-retardant plastic composition can further include a filler such as, for example, talc, calcium carbonate, AgO, ZnO, CaO, MnO, Al(OH)₃, AlO(OH), Mg(OH)₂, kaolinite, wollastonite, mica, glass beads, or any combination thereof.

[0045] In one aspect, the flame-retardant plastic composition has a melt flow rate of from about 7.5 to about 20 g/10 min, or of about 7.5, 10, 12.5, 15, 17.5, or about 20 g/10 min, or a combination of any of the foregoing values, or a range encompassing any of the foregoing values.

[0046] Also disclosed herein is an article including or made from the flame-retardant plastic compositions disclosed herein. In one aspect, the article has an Izod impact resistance at 25 °C of from about 4 to about 7 kJ/m², from about 4 to about 6 kJ/m², from about 6 to about 7 kJ/m², or of about 4, 4.5, 5, 5.5, 6, 6.5, or about 7 kJ/m², or a combination of any of the foregoing values, or a range encompassing any of the foregoing values. In a further aspect, the article can have an Izod impact resistance at -37 °C of from about 6.5 to about 10.5 kJ/m², from about 6.5 to about 8.5 kJ/m², from about 7.5 to about 9.5 kJ/m², or of about 6.5, 7, 7.5, 8, 8.5, 9, 9.5, 10, or about 10.5 kJ/m², or a combination of any of the foregoing values, or a range encompassing any of the foregoing values. In still another aspect, the article can have an elongation at break of from about 45% to about 600%, from about 45% to about 100%, from about 100% to about 300%, from about 300% to about 600%, or of about 45, 100, 150, 200, 250, 300, 350, 400, 450, 500, 550, or about 600%, or a combination of any of the foregoing values, or a range encompassing any of the foregoing values.

[0047] In one aspect, the article can have a critical stress intensity factor at 25 °C of from about 0.9 MPa·m^{-1/2} to about 1.2 MPa·m^{-1/2}, from about 0.9 to about 1.1 MPa·m^{-1/2}, from about 1.0 to about 1.2 MPa·m^{-1/2}, or of about 0.9, 1.0, 1.1, or about 1.2 MPa·m^{-1/2}, or a

combination of any of the foregoing values, or a range encompassing any of the foregoing values. In one aspect, the article can have a tensile strength of from about 15 MPa to about 30 MPa, from about 15 to about 20 MPa, from about 20 to about 30 MPa, or of about 15, 20, 25, or about 30 MPa, or a combination of any of the foregoing values, or a range encompassing any of the foregoing values. In an aspect, the article has a tensile modulus of from about 1700 MPa to about 4300 MPa, from about 1700 to about 2500 MPa, from about 2500 to about 3500 MPa, from about 3500 to about 4300 MPa, or of about 1700, 2000, 2500, 3000, 3500, 4000, or about 4300 MPa, or a combination of any of the foregoing values, or a range encompassing any of the foregoing values. In one aspect, the article has a notched Izod impact strength of from about 80 J/m to about 1100 J/m, from about 100 to about 400 J/m, from about 400 to about 800 J/m, from about 800 to about 1100 J/m, or of about 80, 100, 200, 300, 400, 500, 600, 700, 800, 900, 1000, or about 1100 J/m, or a combination of any of the foregoing values, or a range encompassing any of the foregoing values. In any of these aspects, the article can have a flammability rating of V0 according to test method UL94.

[0048] Also disclosed herein are methods of making the disclosed flame-retardant plastic composition. In a particular aspect, the method includes at least the steps of: (a) admixing the polymeric component, the brominated flame retardant, and the thermoplastic toughener to form a precursor mixture; and (b) extruding the precursor mixture at an elevated temperature.

[0049] In a further aspect, steps (a) and (b) can be carried out by any method known in the art. In one aspect, step (a) and/or (b) is conducted in a twin screw extruder. In a further aspect, the elevated temperature can be from about 160 °C to about 230 °C for polyolefins or polystyrenes, from about 190 to about 210 °C, from about 210 to about 230 °C, or can be about 160, 165, 170, 175, 180, 185, 190, 195, 200, 205, 210, 215, 220, 225, or about 230 °C, or a combination of any of the foregoing values, or a range encompassing any of the foregoing values. The processing temperature can be from about 160 °C to about 345 °C for PPA (polyphthalamide or high temperature nylon). In one aspect, the twin screw extruder has a speed of about 60 rpm to 500 rpm. In another aspect, design and operation of the twin screw extruder encompasses those methods and parameters known to those skilled in the art.

[0050] In some aspects, the flame-retardant plastic compositions can be made by admixing the polymeric component, the brominated flame retardant, and the thermoplastic toughener in a double arm mixer.

[0051] In a further aspect, the method includes at least the steps of: (a) admixing the polymeric component and the brominated flame retardant to make an initial composition known to those skilled in the art as a Master Batch; and (b) mixing the Master Batch and the thermoplastic toughener to form a second final mixture; and (c) extruding the final mixture at an elevated temperature.

[0052] In a further aspect, steps (a), (b) and (c) can be carried out by any method known in the art. In one aspect, steps (a), (b) and/or (c) are conducted in a twin screw extruder. In a further aspect, the elevated temperature can be from about 160 °C to about 230 °C, from about 190 to about 210 °C, from about 210 to about 230 °C, or can be about 160, 165, 170, 175, 180, 185, 190, 195, 200, 205, 210, 215, 220, 225, or about 230 °C, or a combination of any of the foregoing values, or a range encompassing any of the foregoing values. In one aspect, the twin screw extruder has a speed of about 60 rpm. In another aspect, design and operation of the twin screw extruder encompasses those methods and parameters known to those skilled in the art.

[0053] In any of these methods, when a synergist such as, for example, antimony trioxide is used, it can be added at any step during the mixing process.

[0054] Many modifications and other embodiments disclosed herein will come to mind to one skilled in the art to which the disclosed compositions and methods pertain having the benefit of the teachings presented in the foregoing descriptions and the associated drawings. Therefore, it is to be understood that the disclosures are not to be limited to the specific embodiments disclosed and that modifications and other embodiments are intended to be included within the scope of the appended claims. The skilled artisan will recognize many variants and adaptations of the aspects described herein. These variants and adaptations are intended to be included in the teachings of this disclosure and to be encompassed by the claims herein.

[0055] Although specific terms are employed herein, they are used in a generic and descriptive sense only and not for purposes of limitation.

[0056] As will be apparent to those of skill in the art upon reading this disclosure, each of the individual embodiments described and illustrated herein has discrete components and features which may be readily separated from or combined with the features of any of the other several embodiments without departing from the scope or spirit of the present disclosure.

[0057] Any recited method can be carried out in the order of events recited or in any other order that is logically possible. That is, unless otherwise expressly stated, it is in no way intended that any method or aspect set forth herein be construed as requiring that its steps

be performed in a specific order. Accordingly, where a method claim does not specifically state in the claims or descriptions that the steps are to be limited to a specific order, it is no way intended that an order be inferred, in any respect. This holds for any possible non-express basis for interpretation, including matters of logic with respect to arrangement of steps or operational flow, plain meaning derived from grammatical organization or punctuation, or the number or type of aspects described in the specification.

[0058] While aspects of the present disclosure can be described and claimed in a particular statutory class, such as the system statutory class, this is for convenience only and one of skill in the art will understand that each aspect of the present disclosure can be described and claimed in any statutory class.

[0059] It is also to be understood that the terminology used herein is for the purpose of describing particular aspects only and is not intended to be limiting. Unless defined otherwise, all technical and scientific terms used herein have the same meaning as commonly understood by one of ordinary skill in the art to which the disclosed compositions and methods belong. It will be further understood that terms, such as those defined in commonly used dictionaries, should be interpreted as having a meaning that is consistent with their meaning in the context of the specification and relevant art and should not be interpreted in an idealized or overly formal sense unless expressly defined herein.

[0060] Prior to describing the various aspects of the present disclosure, the following definitions are provided and should be used unless otherwise indicated. Additional terms may be defined elsewhere in the present disclosure.

Definitions

[0061] As used herein, "comprising" is to be interpreted as specifying the presence of the stated features, integers, steps, or components as referred to, but does not preclude the presence or addition of one or more features, integers, steps, or components, or groups thereof. Moreover, each of the terms "by," "comprising," "comprises," "comprised of," "including," "includes," "included," "involving," "involves," "involved," and "such as" are used in their open, non-limiting sense and may be used interchangeably. Further, the term "comprising" is intended to include examples and aspects encompassed by the terms "consisting essentially of" and "consisting of." Similarly, the term "consisting essentially of" is intended to include examples encompassed by the term "consisting of."

[0062] As used in the specification and the appended claims, the singular forms "a," "an" and "the" include plural referents unless the context clearly dictates otherwise. Thus, for example, reference to "a polymer," "a brominated flame retardant," or "an article," include, but are not limited to, mixtures or combinations of two or more such polymers, brominated

flame retardants, or articles, and the like.

[0063] It should be noted that ratios, concentrations, amounts, and other numerical data can be expressed herein in a range format. It will be further understood that the endpoints of each of the ranges are significant both in relation to the other endpoint, and independently of the other endpoint. It is also understood that there are a number of values disclosed herein, and that each value is also herein disclosed as “about” that particular value in addition to the value itself. For example, if the value “10” is disclosed, then “about 10” is also disclosed. Ranges can be expressed herein as from “about” one particular value, and/or to “about” another particular value. Similarly, when values are expressed as approximations, by use of the antecedent “about,” it will be understood that the particular value forms a further aspect. For example, if the value “about 10” is disclosed, then “10” is also disclosed.

[0064] When a range is expressed, a further aspect includes from the one particular value and/or to the other particular value. For example, where the stated range includes one or both of the limits, ranges excluding either or both of those included limits are also included in the disclosure, e.g. the phrase “x to y” includes the range from ‘x’ to ‘y’ as well as the range greater than ‘x’ and less than ‘y.’ The range can also be expressed as an upper limit, e.g. ‘about x, y, z, or less’ and should be interpreted to include the specific ranges of ‘about x,’ ‘about y,’ and ‘about z’ as well as the ranges of ‘less than x,’ ‘less than y,’ and ‘less than z.’ Likewise, the phrase ‘about x, y, z, or greater’ should be interpreted to include the specific ranges of ‘about x,’ ‘about y,’ and ‘about z’ as well as the ranges of ‘greater than x,’ ‘greater than y,’ and ‘greater than z.’ In addition, the phrase “about ‘x’ to ‘y’”, where ‘x’ and ‘y’ are numerical values, includes “about ‘x’ to about ‘y’”.

[0065] It is to be understood that such a range format is used for convenience and brevity, and thus, should be interpreted in a flexible manner to include not only the numerical values explicitly recited as the limits of the range, but also to include all the individual numerical values or sub-ranges encompassed within that range as if each numerical value and sub-range is explicitly recited. To illustrate, a numerical range of “about 0.1% to 5%” should be interpreted to include not only the explicitly recited values of about 0.1% to about 5%, but also include individual values (e.g., about 1%, about 2%, about 3%, and about 4%) and the sub-ranges (e.g., about 0.5% to about 1.1%; about 5% to about 2.4%; about 0.5% to about 3.2%, and about 0.5% to about 4.4%, and other possible sub-ranges) within the indicated range.

[0066] As used herein, the terms “about,” “approximate,” “at or about,” and “substantially” mean that the amount or value in question can be the exact value or a value that provides

equivalent results or effects as recited in the claims or taught herein. That is, it is understood that amounts, sizes, formulations, parameters, and other quantities and characteristics are not and need not be exact, but may be approximate and/or larger or smaller, as desired, reflecting tolerances, conversion factors, rounding off, measurement error and the like, and other factors known to those of skill in the art such that equivalent results or effects are obtained. In some circumstances, the value that provides equivalent results or effects cannot be reasonably determined. In such cases, it is generally understood, as used herein, that “about” and “at or about” mean the nominal value indicated $\pm 10\%$ variation unless otherwise indicated or inferred. In general, an amount, size, formulation, parameter or other quantity or characteristic is “about,” “approximate,” or “at or about” whether or not expressly stated to be such. It is understood that where “about,” “approximate,” or “at or about” is used before a quantitative value, the parameter also includes the specific quantitative value itself, unless specifically stated otherwise.

[0067] As used herein, the term “effective amount” refers to an amount that is sufficient to achieve the desired modification of a physical property of the composition or material. For example, an “effective amount” of a thermoplastic toughener refers to an amount that is sufficient to achieve the desired improvement in the property modulated by the formulation component, e.g. achieving the desired level of encapsulation and/or compatibilization of a brominated flame retardant in a polymeric phase. The specific level in terms of wt% in a composition required as an effective amount will depend upon a variety of factors including the amount and type of polymeric component, amount and type of thermoplastic toughener, amount and type of brominated flame retardant, and end use of the article made using the composition.

[0068] As used herein, the terms “optional” or “optionally” means that the subsequently described event or circumstance can or cannot occur, and that the description includes instances where said event or circumstance occurs and instances where it does not.

[0069] A “thermoplastic” polymer becomes plastic, pliable, or moldable upon heating and resolidifies upon cooling. The temperatures at which thermoplastic polymers soften can be different depending on the polymer composition. Thermoplastic polymers exhibit no changes in chemical properties or composition after heating and resolidification. Thermoplastic compositions can be processed using various methods including extrusion, injection molding, thermoforming, and the like.

[0070] An “elastomer” as used herein is a polymer exhibiting elastic or rubber-like properties able to recover its original shape after being stretched or subjected to another applied stress. An elastomeric polymer has a molecular structure that is unorganized and

non-crystalline when at rest. A “thermoplastic elastomer” is a thermoplastic polymer also having elastomeric properties.

[0071] “Test method UL94” refers to a test method produced by Underwriters Laboratories (UL) intended to serve as a preliminary indication of plastic acceptability for use as part of an article with respect to flammability. To achieve a V-0 flammability rating, for example, burning of an article stops within 10 seconds after two applications of ten seconds each of a flame set to a test bar. Flaming drips may not be present.

[0072] Unless otherwise specified, temperatures referred to herein are based on atmospheric pressure (i.e. one atmosphere).

[0073] Now having described the aspects of the present disclosure, in general, the following Examples describe some additional aspects of the present disclosure. While aspects of the present disclosure are described in connection with the following examples and the corresponding text and figures, there is no intent to limit aspects of the present disclosure to this description. On the contrary, the intent is to cover all alternatives, modifications, and equivalents included within the spirit and scope of the present disclosure.

EXAMPLES

[0074] The following examples are put forth so as to provide those of ordinary skill in the art with a complete disclosure and description of how the compounds, compositions, articles, devices and/or methods claimed herein are made and evaluated, and are intended to be purely exemplary of the disclosure and are not intended to limit the scope of what the inventors regard as their disclosure. Efforts have been made to ensure accuracy with respect to numbers (e.g., amounts, temperature, etc.), but some errors and deviations should be accounted for. Unless indicated otherwise, parts are parts by weight, temperature is in °C or is at ambient temperature, and pressure is at or near atmospheric.

Example 1: Polypropylene System, Materials, and Models

Materials and Model Systems

[0075] PP (grade name: Profax 6523, isotactic index ≥ 94 , M_w : 342,000 g/mol, PDI: 9.4) was obtained from LyondellBassel, and BPS (medium M_w , research grade) was donated by Albemarle. The used rubber (grade name: SEBS G1652, Styrene contents: 30 wt. %, M_w : 85,000 g/mol, PDI: 1.2) was received from Kraton.

[0076] In total, six different model systems were prepared as shown in Table 1. The several annotations describing specific model systems refer PP/BPS [L] to a binary system of ‘Large’ BPS particles dispersed in PP, PP/BPS/SEBS [SD] to a ternary system of BPS and

SEBS 'Separately Dispersed' in PP, PP/BPS [S] to a binary system of 'Small' BPS particle dispersed in PP, and PP/BPS/SEBS [CS] to a ternary system of 'Core Shell' structure between BPS and SEBS in PP, respectively based on their morphological observation in **FIGs. 4A-4D**. As a control system, PP was extruded as well before being made into molded specimens to make them have the same thermal history as other model systems. To achieve UL94 V-0 grade for polyolefin, it is known that total bromine needs roughly 18 to 19 wt. %. Therefore, model systems were formulated to have this total amount of bromine wt. %. The amount of SEBS was arbitrarily chosen as 4 wt. % to maximize the encapsulation onto BPS as well as minimize the modulus reduction.

Table 1: Compositional Formulations (wt%) of Model Systems							
Model system		PP/BPS [L]	PP/BPS/SEBS [SD]	PP/BPS [S]	PP/BPS/SEBS [CS]	PP	PP/SEBS
Barrel temperature of extruder (°C)		190	190	230	230	190	190
Component		weight %					
Resin	PP	74	70	74	70	100	96
Flame retardant	BPS	26	26	26	26	-	-
Rubber	SEBS	-	4	-	4	-	4

Extrusion, Injection Molding, and Compression Molding

[0077] All the model systems were extruded in a twin-screw extruder (ThermoFisher Process 11, L/D = 40) with one feeder (two-screw) after hand-blending of PP, BPS pellets and rubber powders in the transparent zip-bag. The total amount fed was 2 kg and the amount collected from the extruder was 1.5 kg. The compositions are shown in Table 1. The extrusion temperature indicates that all barrel zones (Die and Zone 1 - 7) had temperatures of 190 °C or 230 °C, depending on each composition in Table 1. The twin screw speed of the extruder and the single screw speed of the feeder was 60 RPM and 5 RPM, respectively. After extrusion, strands were cooled in a water bath and manually chopped. These chopped pellets were either injection molded (Thermo Scientific HAAKE MiniJet Pro) or compression molded (PHI model PW-22). The injection barrel was set to the same temperature as its extrusion temperature in each model system. The mold temperature and injection pressure (holding pressure) were 60 °C and 670 bar during the cooling time of 15 seconds, respectively. Each model system for SN3PB and DN4PB testing specimens were compression-molded from the mold having the cavity size of 127

mm x 60 mm x 6.4 mm at the same temperature of its extruded temperature under the pressure of 6 MPa and then chilled quickly from the water bath.

Izod Impact Strength

[0078] After the rectangular bar specimens (63.5 mm × 12.7 mm × 3.2 mm) were prepared from the injection molding machine under the processing condition as mentioned in section 2.2., the notch (radius: 250 μm) was machined and the impact test was done at the room temperature (25 °C) by the pendulum type impact machine (Tinius Olson Model 66, striking speed: 2.9 m/s) based on ASTM D256. Individual specimens' thickness and notch depth were carefully measured by micrometers (Mitutoyo Model 543, resolution: 1 μm). Five samples for each model system were measured and then averaged.

Tensile Strength

[0079] Dog-bone shape tensile specimens (ASTM D638, Type IV) were prepared from the same injection molding condition of the Izod impact specimen. Tensile tests were done under the crosshead speed of 5 mm/min at room temperature (25 °C) by a tensile load frame machine (Instron Model 5567, Load Cell: 5 kN) based on ASTM D638. Three specimens were measured and then averaged for the modulus, yield strength, elongation at break.

Critical Energy Release Rate (G_{Ic})

[0080] Eight rectangular specimens (127 mm × 12.7 mm × 6.4 mm) having a straight crack at the center position for each model system were prepared by machining from the compression molded plate, as mentioned in section 2.1. This straight crack includes a machined part and a sharp crack part. A sharp crack was generated using a fresh razor blade sliding from the instrument scratch machine in a linearly progressive normal-load increasing fashion (1 to 50 N). The razor blade sharpened length was similar to all specimens with $600 \pm 50 \mu\text{m}$ and the machined notch length was created differently so that each specimen has a different total initial crack length in the range of $0.3 \leq a/W \leq 0.7$. The geometry of the testing setup is the single edge notch three points bending (SN3PB) under the striking speed of 2.9 m/s. Detailed information about specimen and testing geometry and sharp crack generation is introduced as shown in **FIGs. 1A-2A**.

[0081] The below equations were used to calculate the critical energy release rate at mode I (G_{Ic}).

[0082] By the definition of compliance and energy release rate,

$$U = \frac{1}{2} P^2 \cdot C \text{ (Eq. 1)}$$

$$G_c = \frac{1}{B} \cdot \frac{dU}{da} \text{ (Eq. 2)}$$

[0083] By combining Eq. 1 and Eq. 2,

$$U = G_c B W \phi \text{ (Eq. 3)}$$

$$\alpha = a/W, \phi = \frac{c}{dc/da} \text{ (Eq. 4)}$$

where variables used are defined as follows: P: load, U: energy for fracture, C: compliance, B: sample thickness, a: initial crack length, W: sample width, ϕ : energy calibration factor, G_c : critical energy.

$$U_t = U + U_0 \text{ (Eq. 5)}$$

[0084] When the pendulum head strikes a SN3PB specimen, the generated total energy, U_t , contains an additional energy term, U_0 , which is not contributing to the energy dissipation with the new surface creation by fracture. U_0 includes kinetic energy when a broken specimen flies away, frictional energy between the sample and the fixture, sound energy, et cetera. U_0 was calculated by striking one more time by floating the broken specimen into the fixture as shown in FIG. 1D. The frictional energy additionally generated between the fractured specimen and the assisting bars was assumed to be neglected.

[0085] To get the precise calibration energy factor in the generalized SN3PB geometry condition, Guinea's compliance function for load-point was applied, independent of any span length.

[0086] To obtain the energy calibration factor, differentiation of the compliance function is required. The format of the derivative term (dC/da) in the energy calibration factor (ϕ) was calculated from the compliance functions in Table 2 by Wolfram Mathematica software. The total initial crack length a of every specimen was measured by a hand-held traveling microscope (Dinolite AM311S), as shown in FIG. 2B. Once fracture energy values (U) for eight samples for each model system are plotted with their normalized areas ($BW\phi$), the slope is the critical energy release rate (G_{lc}).

Table 2: Mathematical Expressions for Compliance Function	
$C = C_{cr} + C_0$	
Cracked compliance	$C_{cr} = \frac{1}{EB} \left[c_1(\alpha) + \frac{S}{W} \cdot c_2(\alpha) + \left(\frac{S}{W} \right)^2 \cdot c_3(\alpha) \right]$
	$c_1(\alpha) = -0.378\alpha^3 \ln(1 - \alpha) + \alpha^2 \frac{0.29 + 1.39\alpha - 1.6\alpha^2}{1 + 0.54\alpha - 0.84\alpha^2}$

	$c_2(\alpha) = 1.1\alpha^3 \ln(1 - \alpha) + \alpha^2 \frac{-3.22 - 16.4\alpha + 28.1\alpha^2 - 11.4\alpha^3}{(1 - \alpha)(1 + 4.7\alpha - 4\alpha^2)}$
	$c_3(\alpha) = -0.176\alpha^3 \ln(1 - \alpha) + \alpha^2 \frac{8.91 - 4.88\alpha - 0.435\alpha^2 + 0.26\alpha^3}{(1 - \alpha)^2(1 + 2.9\alpha)}$
Non-cracked compliance	$C_0 = \frac{1}{4EB} \left(\frac{S}{W} \right)^3 \left[1 + 2.85 \left(\frac{W}{S} \right)^2 - 0.84 \left(\frac{W}{S} \right)^3 \right]$

Qualitative Toughening Mechanism Test

[0087] The specimen preparation for double edge notch four points bending (DN4PB) tests is the same as for SN3PB. One difference is that specimens have two sharp cracks, as shown in FIG. 3A. The instrumented scratch machine made two sharp cracks that are nearly but not perfectly identical. During the impact striking process of the four points bending, both cracks will have similar damage process zones even though one is propagated and the other is arrested. foam type dampers (thickness: 3 mm) were used to minimize asymmetric hitting from the two points contacts between the striking head and the specimen as shown in FIG. 3B. This technique is useful to observe a sub-critically fractured features, which represents the phenomena just before the crack propagation. Fractographical observations are checked firstly in an optical microscope (OM) with the technique of petrographic thin sections to see the global view of the damage zones and then checked with a transmission microscope (TEM) to see micro damaging (or toughening) features. Mid-plane sectioning was done using a diamond saw (Buhler ISOMET 1000). One side of the mid-plane section is embedded in the epoxy and attached to the glass slide and carefully polished up to 80 μm for the optical microscopic observation in FIG. 3D. The other side is embedded in the epoxy block for TEM observation.

Optical Microscopy

[0088] The imaging process of the transmission mode under the bright field (TOM) and under the cross polarizers (POM) was conducted for the polished samples attached onto a glass slide in an optical microscope (Olympus BX60) after being prepared through the petrographic methodology as shown in FIG. 3D. No additional filters were applied.

Staining Process and TEM Microscopy

[0089] A pre-staining method was applied to differentiate different phases. The styrene phases in SEBS rubber are known to be stained by RuO_4 . Embedded block faces were trimmed and cryogenically polished using a diamond knife at - 60 $^\circ\text{C}$ to prevent smearing. Cryo-polished blocks were then stained with the vapor phase of a 2 % aqueous RuO_4 solution for 4 hrs at ambient temperature. The staining solution was prepared using

ruthenium (III) chloride hydrate ($\text{RuCl}_3 \times \text{H}_2\text{O}$) with 5.25% aqueous sodium hypochlorite into a glass jar with a screw lid. After staining, the embedded block was placed in deionized water overnight prior to sectioning to allow residual RuO_4 to dissipate from the sample. The stained block face was thin-sectioned to thickness of 120 nm with a diamond knife having a water boat and several thin sections were moved onto a copper grid in a microtome machine (Leica EM UC7 Ultramicrotome) at ambient temperature. TEM imaging was processed by JEOL 1200X under the electron beam voltage of 100 keV. BPS particle size for each model system was averaged out from three different TEM images.

Surface Energy Measurement

[0090] Surface energy analysis for BPS was performed using an iGC Surface Energy Analyzer, SEA (Surface Measurement Systems) and the data values were analyzed using SEA Analysis Software packages. Measurement steps are briefly summarized here but detailed methodology can be found in several references. Roughly 150 mg of BPS powder samples was packed into individual silanized glass columns. The total surface area of the powder samples was determined with the probe molecules as nm then different amount of probe molecules were injected into the columns. The normalized surface area is expressed as n/nm. In the next steps, different series of probe molecules were injected into the column after reconditioning with helium gas prior to each experiment to measure the retention time. The measured retention time of probe molecules interacting with powder materials in the column of iGC was converted into the net retention volume by using James and Martin correction factor. The Gibbs free energy of adsorption was calculated by plugging the net retention volume into Henry's law, where the free energy of adsorption is related as to the work of adhesion onto the surface of the powder materials. The detailed information is shown in the following literature. Non-polar probe molecules (heptane, octane, nonane, and decane) and polar probe molecules (dichloromethane, ethyl acetate, acetone, acrylonitrile, and ethanol) were applied to determine the dispersive surface energy (γ^d) as well as the polar surface energy (γ^p), respectively. All experiments were conducted at 30 °C. Methane gas was used for the dead volume corrections. For the determination of dispersive and polar term of the surface energy, the method of Dorris and Gray and Good-van Oss-Chaudhury model was employed. The resultant dispersive and polar terms of surface energy of BPS are introduced in Table 3. γ_{10} , γ_{50} and γ_{90} mean the values corresponding to the area portion under the surface energy plot along the coverage fraction by using exponential decay function, where the distribution of the surface energy is attributed to the defects and imperfections of surfaces. The γ_{50} value is widely chosen as a representative value of surface energy. The value of $-d\gamma/dT$ for BPS is calculated based on the linear approximation from the plot the density values from the Equation 6.

$$\gamma(T) = \gamma(298) \left[\frac{\rho(T)}{\rho(298)} \right]^4 \quad (\text{Eq. 6})$$

[0091] The density values of BPS measured at the temperature of 25, 40, 50, 60 and 70 °C with a silicone oil in a pycnometer was 2.22, 2.20, 2.18, 2.17 and 2.16, respectively.

Table 3: Measured Surface Energy Values for BPS					
Type	Min.	Max.	γ_{10}	γ_{50}	γ_{90}
γ^d	32.7	82.6	33.8	42.0	62.1
γ^p	2.8	11.2	2.9	4.4	7.7
γ	35.5	93.8	36.7	46.4	69.8
Polarity	0.1	0.1	0.1	0.1	0.1

Table 4: Surface Energy Data for PP, SEBS, and BPS					
	γ (mJ·m ⁻²)	γ^d (mJ·m ⁻²)	γ^p (mJ·m ⁻²)	Polarity (γ^p/γ)	$d\gamma/dT$ (mJ·m ⁻² ·°C ⁻¹)
SEBS (at 30 °C)	34.2	29.0	5.1	0.15	0.067
PP (at 20 °C)	30.1	30.1	0	0	0.058
BPS (at 30 °C)	46.4	42.0	4.4	0.1	0.054

Example 2: Polypropylene System, Results and Discussion

Morphological Analysis

[0092] The glass transition (T_g) of BPS is known to be in the range of 163 to 182 °C. Both processing temperatures of 190 and 230 °C are higher than the T_g . The first clear observation shown in **FIGs. 4A** and **4C** is the size change of the BPS particle at different temperature in the PP/BPS binary system. It is seen that the degree of mixing occurs more easily due to the decrease in the viscosity of BPS at a high processing temperature, which might induce better dispersion kinetically. From this observation, it is confirmed that PP and BPS are an immiscible polymer blend. Miscible polymers with BPS are rare.

[0093] Ternary polymer blend systems of PP, BPS and SEBS have not only particle size differences of BPS but also there are significant morphological difference in **FIGs. 4B** and **4D**. With the processing temperature of 190 °C, BPS and SEBS are separately dispersed. On the other hand, BPS particles are encapsulated by SEBS rubbers in addition to good dispersions of smaller BPS particles. For the samples that were stained with RuO₄, the darker phase is SEBS due to the higher electron density of ruthenium vs bromine. To further investigate the fundamental reasons for morphological differences, thermodynamic

spreading theory was applied. Since Hobbs proposed the modified Harkins equation, the morphological estimations by this model have been well matched with the experimental observation for ternary polymer blends. Total surface energy and its dispersive and polar terms of chosen materials for BPS, PP and SEBS are shown in Table 3 and FIG. 4A. Each interfacial energy (γ_{ij}) is calculated by the harmonic equation as shown below.

$$\gamma_{ij} = \gamma_i + \gamma_j - 4 \left[\frac{\gamma_i^d \gamma_j^d}{\gamma_i^d + \gamma_j^d} + \frac{\gamma_i^p \gamma_j^p}{\gamma_i^p + \gamma_j^p} \right] \text{ (Eq. 7)}$$

$$S_{ik} = \gamma_{kj} - \gamma_{ij} - \gamma_{ik} \text{ (Eq. 8)}$$

where i, j and k represent component BPS, PP, or SEBS; γ_i : surface energy of i; γ_{ij} : Interfacial energy between i and j; and S_{ik} : spreading coefficient for i and k to j.

[0094] When the spreading coefficients, S_{ik} satisfies with certain conditions in FIG. 5E, the two minor phases determine their stable locations. Some important preconditions must be met for this concept to apply. Each polymer should be immiscible and quenching is fast enough to maintain the morphology for the molded samples. Both of these conditions are met for our samples.

[0095] The dispersive and polar component of surface energy of BPS are shown in Table 3 and FIGs. 2A-2B. The γ_{10} , γ_{50} and γ_{90} mean the values corresponding to the area portion under the surface energy plot by using exponential decay function. The distribution of the surface energy depending on the fractional surface coverage is caused by the imperfection of the BPS surface such as defects. The γ_{50} is chosen as the representative value to the equation of spreading coefficient for the morphological estimation. Spreading coefficient, $S_{BPS-SEBS}$ maintains negative values in the whole range of temperature. On the other hand, spreading coefficient, $S_{SEBS-BPS}$ becomes to be positive above the temperature of 220 °C, which means that core-shell morphology is thermodynamically favored. This estimation is consistent with the result of TEM observation.

Izod Impact and Tensile Behavior

[0096] Izod impact strength is an easy and fast screening tool to compare the relative ranking of which system is better for impact property. PP/BPS/SEBS[SD] system has no improvement compared to PP/BPS[S]. One possible scenario is that the crack propagation is governed by the large particles either by passing through the weak interface or splitting the rigid particles. On the other hand, PP/BPS/SEBS[CS] had a significant improvement compared to the other three model systems containing BPS and its impact strength gets close to PP/SEBS. Rubber coated BPS particles appear to play a role of toughening agents.

[0097] In tensile behavior, samples of PP/BPS[L] and PP/BPS/SEBS[SD] containing large BPS started breaking just after yielding. PP/BPS[S] and PP/BPS/SEBS[CS] showed the phenomena of necking propagation after yielding, while PP/BPS[L] and PP/BPS/SEBS[SD] showed no necking. Interestingly, there are same amount of SEBS formulated into PP/BPS/SEBS[SD] and PP/BPS/SEBS[CS], they have quite different modulus. PP/BPS/SEBS[CS] has even lower modulus than PP and it is comparable to the modulus of PP/SEBS. Therefore, in this uniaxial far field stress condition, the matrix is mostly influenced at the interface boundary with SEBS but not BPS, which is indirect evidence that this rubber encapsulated BPS particles behave like rubber particles. Matonis et al confirmed that when the coated rubber thickness exceeds roughly 4% of the radius of rigid particles, the modulus was getting close to the binary polymer system having only rubbers based on their analytical study.

Table 5: Tensile Properties						
Model system	PP/BPS [L]	PP/BPS/SEBS[SD]	PP/BPS [S]	PP/BPS/SEBS[CS]	PP	PP/ SEBS
Modulus (GPa)	1.63 ± 0.01	1.52 ± 0.02	1.62 ± 0.03	1.27 ± 0.04	1.45 ± 0.08	1.27 ± 0.01
Yield strength (MPa)	28.5 ± 1.1	27.5 ± 0.6	28.6 ± 1.1	27.0 ± 1.4	34.9 ± 1.2	31.1 ± 0.2
Elongation at break (%)	47 10	55 28	304 ± 37	251 ± 90	500 ± 70	587 ± 97

Critical Energy Release Rate (G_{IC}) and Toughening Mechanism

[0098] Izod and Charpy impact strength have several limitations for the geometrical dependency such as notch radius and length, span length, specimen thickness and so on. Therefore, much effort was made to obtain the geometrical independent fracture toughness parameter in the impact condition. The critical energy release rate is the intrinsic fracture toughness value based on linear elastic fracture mechanics [LEFM]. Large particle dominant systems (PP/BPS[L] and PP/BPS/SEBS[SD]) show the lower fracture toughness than even the PP system. This means that the resistance for the propagation of sharp crack tip in those large particle systems was so low that materials behave in more brittle manner than the matrix polymer. In FIGs. 8A and 8C, a crack penetrates through BPS particles and there is no restraining mechanism for the crack, which is a typical brittle failure for rigid particle incorporated systems. PP/BPS[S] system also shows the significant drop for fracture toughness in FIG. 7C. Crazes, which are typical damages behavior in front of the crack tip for the thermoplastic materials, are even more suppressed than in PP as shown in FIGs. 9A and 11A. However, PP/BPS/SEBS[CS] shows a significant improvement for

the fracture toughness. This is possibly attributed to the shear banding generation through the massive crazing formations. Shear yielding would be initiated due to the relief of triaxial stress constraint through the volume dilation. Here, the massive crazes are the main trigger for the volume dilatation. For the clear investigation of the micro-toughening mechanism for PP/BPS/SEBS[CS], TEM was performed from the other part of the arrested crack after DN4PB testing **FIG. 10**. Direct evidence that massive crazes were initiated and stabilized from the rubber coated BPS particles was found. As more stress was built up with the volume dilation, shear banding occurred. Therefore, our proposed mechanism is crazing/shear banding as shown in **FIGs. 12**. Even though rubber encapsulated BPS indeed plays a role as a toughener, its toughening mechanism is a bit different. As shown in **FIGs. 11C-11D**. The cavitation of SEBS rubbers is preceded, and volume dilatation is performed with crazing, then followed by shear banding mechanism. Similar mechanism can be found in the reference.

Conclusion

[0099] We were successful in our effort to prepare BPS particles that were encapsulated with SEBS rubber by careful choice of processing conditions. Morphological differences between core-shell structure and independent dispersed structure in the ternary polymer blend of PP, BPS, and SEBS was consistent with the analysis of the theoretical estimation using thermodynamic spreading theory. It was confirmed that SEBS rubber significantly improved the fracture toughness by encapsulating rigid BPS particles and emulsifying the dispersion of BPS as a compatibilizer. Therefore, the proof of concept that rubber-coated BPS serves as a toughening agent was validated. The toughening mechanisms include the promotion of crazing initiation/shear banding. Rubber-coated BPS therefore acted as both a toughening agent and a compatibilizer.

Example 3: LLDPE System, Materials, and Models

Materials

[0100] LLDPE (grade: Petrothene GA564189) was purchased from LyondellBasell Industries. BPS was supplied by Albemarle Corporation. SEBS rubber (grade: Kraton FG1901, a maleic anhydride grafted SEBS) was kindly donated by Kraton Corporation. All were used as received in pellet form.

Sample Preparation

[0101] Polymer blend compositions and processing conditions are described in Table 6. LLDPE/BPS has a fixed weight ratio of 75:25 with addition of different amounts of SEBS rubber as compatibilizer. For a certain composition, all pellets were added together in a

single step into a twin-screw Haake mixer (Rheocord system 40, Haake Buchler). Each composition was blended for 7 minutes at a certain temperature with a fixed screw speed of 60 rpm.

Table 6: Summary of Blend Composition and Processing Temperature				
System	Processing temperature	Composition by weight fraction		
		LLDPE /g	BPS /g	SEBS /g
LLDPE	185 °C	100	-	-
0 phr/185 °C	185 °C	75	25	0
4 phr/185 °C		75	25	4
8 phr/185 °C		75	25	8
0 phr/230 °C	230 °C	75	25	0
4 phr/230 °C		75	25	4
8 phr/230 °C		75	25	8

[0102] The blended resins were then injection molded into tensile bars (ASTM D638 Type V) and rectangular bars (63.5 mm × 12.7 mm × 3.2 mm) for mechanical testing. Injection molding was performed using a Haake MiniJet Pro Piston Injection Molder (Thermo Fisher Scientific Inc.) with a cylinder temperature of 190 °C, a mold temperature of 60 °C and an injection pressure of 680 bar.

Characterization

Morphology

[0103] An Olympus BX60 optical microscope (OM) was used to observe the micro-scale morphology. The sample (5 mg) was placed between two glass slides and then hot pressed at 190 °C into a thin film for OM observation.

[0104] Transmission electron microscopy (TEM) images were obtained for nano-scale morphology observation using a JEOL JEM-1200, operated at 100 keV. Ultrathin sections with a thickness of 100 nm were prepared using a Reichert-Jung Ultracut E ultra-microtome with a diamond knife at a cryogenic temperature.

Rheology

[0105] Rheological measurements were performed using a TA Instruments ARES-G2 rheometer. Parallel plates with 25 mm diameter were used. Strain sweep measurements were first performed to determine the linear viscoelastic region and then frequency sweep from 100 rad/s to 0.1 rad/s was measured at 230 °C under nitrogen gas protection.

Mechanical Testing

[0106] Tensile property was measured using an Instron universal testing machine. Tensile bars (ASTM D638 Type V) were uniaxially stretched with a crosshead speed of 25.4

mm/min and the gauge length change was monitored by an extensometer. The engineering stress-engineering strain plots were used to calculate modulus, yield strength and elongation at break. The secant modulus at a strain of 1% was measured. At least five specimens were tested for each system and the average value was reported.

[0107] Notched Izod impact test at -37 °C was performed using a Tinius Olsen plastic impact tester according to ASTM D256. A 22.6 J pendulum hammer was used. V-notched specimens (63.5 mm×12.7 mm×3.2 mm) were firstly pre-conditioned at -37 °C for 1 hour in an environmental chamber (Standard Environmental System, Inc.) attached to the impact tester. Once the environmental chamber was open, the specimen was immediately struck by the pendulum hammer to minimize the warming of specimen. The energy absorbed was used to calculate the impact strength. At least five specimens were tested for each system and the average value was reported.

Toughening Mechanism Characterization

[0108] Double-notch four-point bending (DN-4PB) specimens were prepared as described in **FIGs. 13A-13C**. Specimens were first notched with a notch cutter to a depth of 2.54 mm, followed by tapping two nearly identical sharp pre-cracks using fresh razor blades chilled in liquid nitrogen. DN-4PB Charpy impact test were conducted at -37 °C on the pendulum impact tester with a double-head striker. One pre-crack would eventually break and the other one would survive. The surviving crack was thin-sectioned for the observation of the damage zone under both bright field and cross-polarization OM, while the fracture surfaces were investigated using a JEOL JSM-7500F field emission scanning electron microscopy (SEM), operated at 5.0 kV.

Example 4: LLDPE System, Results and Discussion

Morphology

[0109] **FIG. 14** shows the effects of SEBS addition and processing temperature on the morphology. When LLDPE and BPS are blended at 185 °C, the particle size of dispersed BPS phase in this non-compatible system can be as large as 40 µm. The shape of the dispersed BPS phase appears to be irregular rather than spherical. Addition of SEBS slightly improves the dispersion of BPS, but its particle size is still as large as 10 – 20 µm. When LLDPE and BPS are blended at a higher temperature of 230 °C, the BPS particles become uniformly dispersed with a particle size of less than 5 µm. When they are blended at 230 °C with addition of SEBS rubber, the dispersion state is further improved, and BPS particle size becomes too small to be detectable under OM. A further morphological investigation on the well-dispersed 8 phr/230 °C system using TEM suggests that BPS particle size can be reduced to less than 0.5 µm (**FIGs. 15A-15B**).

[0110] The combined effects of addition of SEBS rubber and choice of a suitable processing temperature result in the significant improvement on the dispersion of BPS in LLDPE. It has been reported that viscosity ratio can significantly influence the morphology of immiscible polymer blends. Fine dispersions are usually achieved, and better mechanical properties can be obtained if the viscosity ratio is close to one. When LLDPE/BPS are melt-mixed at a typical processing temperature for LLDPE such as 185 °C ($< T_{cf}$ of BPS), BPS is not fully molten. But if LLDPE/BPS are melt-mixed at 230 °C, the viscosity ratio is 2.3, closer to unity (Table 7). This viscosity ratio of 2.3 contributes to a significant improvement in dispersion. Higher processing temperatures (> 230 °C) were not investigated because of LLDPE degradation. Once an optimal processing temperature is determined, addition of SEBS copolymer can further help improve the compatibility between LLDPE and BPS phases since SEBS copolymer has ethylene/butylene and styrene segments which have good affinity to LLDPE phase and BPS phase, respectively. SEBS copolymer resides at the interface between LLDPE and BPS phases and forms a shell layer covering the dispersed BPS particle, contributing to the formation of the core-shell structure (FIGs. 15A-15B).

Table 7: Viscosities of Neat LLDPE and BPS and Their Viscosity Ratio at Different Temperatures			
Temperature /°C	η^* at $\omega=6.3$ rad/s (Pa·s)		Viscosity ratio ($=\eta^*(BPS)/\eta^*(LLDPE)$)
	BPS	LLDPE	
185	unmolten	375	-
210	8370	300	28
230	530	225	2.3

Rheology

[0111] The influence of different morphologies as a result of different processing temperatures and SEBS rubber addition on the rheological behavior was investigated. The complex viscosities of these systems as a function of angular frequency are shown in FIG. 16. Adding BPS into LLDPE will increase the viscosity in the low frequency region because of the higher viscosity of BPS. Even for the poorly dispersed systems blended at 185 °C, addition of SEBS rubber will slightly increase the viscosity because of the slightly reduced BPS particle size and thus more interfacial areas in the 4 phr/185 °C and 8 phr/185 °C systems, compared to 0 phr/185 °C system. This viscosity increase in the low frequency region becomes much more significant in the well-dispersed systems that are blended at 230 °C. The well-dispersed 8 phr/230 °C system shows the highest viscosity in the low frequency region. Such an increase in viscosity as a result of SEBS rubber compatibilization can be attributed to three reasons: reduced BPS droplet size, narrower BPS particle size distribution, and most importantly, a stronger interfacial interaction

between BPS particles and LLDPE matrix phase. The rheological responses agree well with the earlier morphological observations.

[0112] Cole-Cole plots also show drastically different relaxation characteristics between poorly dispersed and well dispersed systems (FIG. 17). Polymers with a single relaxation process will appear as a semicircle in Cole-Cole plot while a second peak indicates the existence of a different relaxation mechanism. The poorly dispersed 4 phr/185 °C and 8 phr/185 °C systems show two peaks, locating between the characteristic relaxation peaks of neat LLDPE and neat BPS. It suggests that 4 phr/185 °C and 8 phr/185 °C are only partially compatibilized to a very limited level. On the other hand, well-dispersed 4 phr/230 °C and 8 phr/230 °C systems only show a single semicircle, suggesting they have a single relaxation mechanism due to effective compatibilization. Compared to 4 phr/230 °C, 8 phr/230 °C shows a slight right-shift of relaxation peak, indicating a longer relaxation time, probably due to more interfacial entanglements when more SEBS rubber is added. The rheological measurements suggest that morphological uniformity and interfacial interaction can be significantly enhanced in the well-compatible systems, like 8 phr/230 °C.

Mechanical Properties

[0113] Engineering stress - engineering strain plots are shown in FIG. 18. Well-dispersed systems blended at 230 °C consistently display higher tensile yield stress and better elongation at break than their poorly dispersed counterparts blended at 185 °C (Table 8). Generally, due to higher rigidity of BPS, incorporation of BPS into LLDPE will lead to modulus increase. But further addition of softer SEBS rubber phase into LLDPE/BPS will reduce modulus gradually. The modulus of 0 phr/230 °C is almost the same as that of 0 phr/185 °C and the normalized degree of crystallinity of LLDPE is around 23% for all systems. These facts suggest that processing at 230 °C does not cause significant degradation of either polymer. Interestingly, both 4 phr/230 °C and 8 phr/230 °C show lower modulus than their counterparts blended at 185 °C. Since there is no significant polymer degradation or difference in crystallinity, this can only be explained by their morphological differences. In the well-dispersed 4 phr/230 °C and 8 phr/230 °C systems, the SEBS rubber will wrap rigid BPS particles and form a core-shell structure with BPS core and SEBS shell while some SEBS chains will penetrate into and mix with BPS core phase. The modulus of BPS core will be softened by these SEBS polymer chains, causing the overall modulus to become slightly lower. It is also possible that the core-shell morphology of having SEBS to wrap around BPS may cause SEBS wrapped BPS to behave like a rubber and the contribution of rigid BPS core to stiffness is masked by soft SEBS shell, which reduces the overall modulus. On the other hand, in the poorly dispersed 4 phr/185 °C and 8 phr/185 °C systems, the core-shell structure is not formed, and most SEBS rubber particles stay in

LLDPE phase (FIG. 21B). Therefore, rigid BPS particles are not softened by SEBS rubber, causing the poorly dispersed systems to display slightly higher modulus than their well-dispersed counterparts.

Table 8: Summary of Izod Impact Strength and Tensile Properties

System	Impact strength / (kJ/m ²)	Modulus (1% secant) / MPa	Yield strength / MPa	Elongation at break / %
LLDPE	unbroken	357 ± 17	11.4 ± 0.4	342 ± 26
0 phr/185 °C	4.55 ± 0.31	445 ± 6	9.4 ± 0.3	36 ± 6
4 phr/185 °C	3.71 ± 0.50	410 ± 4	10.6 ± 0.1	64 ± 12
8 phr/185 °C	4.02 ± 0.63	368 ± 16	10.0 ± 0.1	96 ± 23
0 phr/230 °C	2.78 ± 0.14	465 ± 28	11.5 ± 0.4	56 ± 2
4 phr/230 °C	8.31 ± 1.65	365 ± 12	12.7 ± 0.2	79 ± 15
8 phr/230 °C	10.33 ± 1.90	322 ± 4	11.9 ± 0.3	125 ± 9

[0114] Notched Izod impact tests at -37 °C were used to evaluate their impact resistance in cold environment (FIG. 19 and **Error! Reference source not found.**). If blended at 185 °C, the poorly dispersed systems show little improvement on the impact strength even with the addition of SEBS rubber. But if blended at 230 °C, their impact strength will be significantly increased with addition of SEBS rubber. Higher toughness can be achieved if more SEBS rubber is added in these well-dispersed systems. Among them, the 8 phr/230 °C system shows impact strength of 10.33 kJ/m², almost 4 times that of 0 phr/230 °C non-compatible system.

Fracture Mechanism Study

[0115] To help understand the toughening mechanisms, the DN-4PB Charpy impact testing was performed. The two nearly identical pre-cracks shall have the same probability to grow when the specimen is struck. One of these two pre-cracks will eventually fail and fracture while the other one will survive and only grow subcritically. Since the surviving pre-crack also undergoes crack propagation in front of its crack tip, observation of the damage zone in front of the crack tip becomes highly informative for understanding the toughening mechanisms of these systems. FIGs. 20A-20D show the damage zones in front of crack tips of 8 phr/185 °C and 8 phr/230 °C systems, observed under both bright field and crossed polars. In the 8 phr/185 °C system, the crack propagates in a brittle manner and it breaks through large BPS particles directly. These large aggregates of BPS are defects through which crack can easily break, resulting in little energy absorption. However, for the well-dispersed 8 phr/230 °C system, large scale crazing has been observed under bright field OM. Such a high intensity of crazing is beneficial for energy absorption, contributing to the much higher impact strength of 8 phr/230 °C system. Additionally, under the cross-polarized light, a birefringent zone is observed in the damage zone of 8 phr/230 °C system

while it is not observed in 8 phr/185 °C system. This indicates that shear banding has occurred during crack propagation, which might be triggered by the cavitation of core-shell rubber.

[0116] Besides observation of damage zones in front of crack tips, fracture surface analysis can also provide useful information regarding toughening mechanisms. **FIGs. 21A-21D** show the fracture surfaces of 8 phr/185 °C and 8 phr/230 °C systems observed under SEM. Large BPS particles break in a brittle fashion in the 8 phr/185 °C system, consistent with observations in **FIG. 21B**. Debonding of BPS particles from LLDPE matrix is also observed, indicating the poor adhesion between BPS and LLDPE phases in the poorly dispersed 8 phr/185 °C system. In addition, there are many small spherical particles distributed in LLDPE matrix phase and debonded from LLDPE phase. These spherical particles might be SEBS rubber that is dispersed in LLDPE phase instead of wrapping around BPS particles due to insufficient melt mixing at 185 °C. However, in the well-dispersed 8 phr/230 °C system, small BPS particles wrapped by SEBS rubber are uniformly distributed. More importantly, these particles are firmly embedded within LLDPE matrix, showing a strong interfacial adhesion to LLDPE, consistent with previous rheological findings.

[0117] The present work studied the morphological, interfacial, and mechanical properties of LLDPE/BPS blends compatibilized and toughened by SEBS rubber. If melt-mixed at a suitable processing temperature (230 °C), the Izod impact strength at -37 °C of the LLDPE/BPS/SEBS blend (75/25/8 by weight) can be improved by almost three times, compared to the non-compatibilized system. The low cost and simple process presented here has the potential to expand the range of LLDPE applications to those requiring flame retardancy and low temperature impact resistance.

Conclusion

[0118] The objective of this work was to compatibilize and improve the properties of LLDPE/BPS polymer blends. The morphology and properties can be affected significantly by not only addition of SEBS rubber as compatibilizer but also processing temperature. Melt-mixing at 230 °C allows the viscosity ratio to be closer to one and addition of SEBS rubber further reduces the BPS particle size to less than 0.5 µm, forming a core-shell structure. This fine morphology and strong interfacial interaction that has been characterized by rheology, contribute together to the three-fold increase of the Izod impact strength at -37 °C. DN-4PB investigations reveal that crazing and cavitation of core-shell rubber induced shear banding are two primary toughening mechanisms for the well dispersed system. The ease of processing makes this work valuable for the production of

ignition resistant LLDPE. Future work will investigate the influence of different morphologies or BPS particle sizes on the fire retardancy of these systems.

Example 5: Additional Compositions using Commercially Available Polymers

Materials

[0119] Flame-retardant plastic compositions according to the present disclosure were produced using the following commercial polymers:

Table 9: Commercial Materials	
Polypropylene homopolymer	LyondellBasell, Profax-6523 (homoPP)
Polypropylene copolymer	LyondellBasell, Profax-7523 (coPP1) Lone Star Chemical, StarPlas PPCO 20NB (coPP2)
LLDPE	LyondellBasell, Petroethene GA564189
Polystyrene	AmSty - Americas Styrenics LLC, Styron 666D
Polyphthalamide (PPA)	Dupont, HTN-502 (Polyamide 6T/66 copolymer, molar ratio of 6T:66=55:45, melting point=310 °C)
Hydrogenated nitrile butadiene rubber	Zeon chemicals, Zetpol 1020L
Brominated flame retardant	Ethylene-1,2-bis(pentabromophenyl) (EBP) Commercial brominated polystyrene 1 (BPS1) Commercial brominated polystyrene 2 (BPS2) Ethylene-bis-tetrabromophthalimide
Maleic anhydride grafted polypropylene	SI Group, Polybond 3200
Polyolefin Elastomer (POE)	Dow chemical, Engage XLT 8677 Dow chemical, Engage 8200 Dow chemical, Engage 8407 SK functional polymer, Lotader 4700T (Maleic anhydride grafted ethylene-ethyl acrylate) SK functional polymer, Lotader AX8930 (Glycidyl methacrylate grafted ethylene-methacrylate)
Styrene-Ethylene Butylene-Styrene block copolymer (SEBS)	Kraton, G1652, Ratio of Styrene/Ethylene Butylene=70/30, MFI: 6 g/10 min at 230 °C, 5kg Kraton, G1657, Ratio of Styrene/Ethylene Butylene=13/87, MFI: 22 g/10 min at 230 °C, 5kg Kraton, A1535H, Ratio of Styrene/Ethylene Butylene=56/44, MFI: <1 g/10 min at 230 °C, 5kg) Kraton, MD6951M, Ratio of Styrene/Ethylene Butylene=34/66, MFI: 36-50 (g/10 min at 230 °C, 2.16kg) Kraton, G1642H, Ratio of Styrene/Ethylene Butylene=20/80, MFI: <1 (g/10 min., at 230 °C, 2.16kg) Kraton, G1643V, Ratio of Styrene/Ethylene Butylene=20/80, MFI: 14-25 g/10 min., at 230 °C, 2.16kg

	Kraton, MD1648V, Ratio of Styrene/Ethylene Butylene=20/80, MFI: 30-46 g/10 min., at 190 °C, 2.16kg) Kraton, G1657V, Ratio of Styrene/Ethylene Butylene=13/87, MFI: 22 g/10 min., at 230 °C, 5kg Kraton, G1645V, Ratio of Styrene/Ethylene Butylene=12.5/87.5, MFI: 2-4.5 g/10 min at 230 °C, 2.16kg
Styrene-Butadiene-Styrene block copolymer (SBS)	Kraton, D1152E, Ratio of Styrene/Butadiene=29.5/70.5, MFI: 3.5-13.5 g/10min at 200 °C/5kg Kraton, D1116A, Ratio of Styrene/Butadiene=23/77 Kraton, DX410J, Ratio of Styrene/Butadiene=18/82
Maleic anhydride grafted SEBS	Kraton, FG1901G Kraton, FG1924G
Glycidyl methacrylate grafted SEBS	Graft Polymer, SEBS-g-GMA 02520 IM
Styrene-Ethylene Propylene-Styrene block copolymer (SEPS)	Kraton, G1730, Ratio of Styrene/Ethylene Propylene=21/79, MFI: 11.2 g/10min at 230 °C, 5 kg
Thermoplastic polyurethane (TPU)	BASF, Elastollan SP9339 (Polyester type) BASF, Elastollan 1195A (Polyether type)
Antimony trioxide	HB Chemical, Antimony trioxide (ATO1) SICA Chauny, Antimony trioxide (ATO2)
Talc mineral	Imerys, Mistrion Vapor R

Experimental Procedures

[0120] Examples from composition 1 to composition 9 (see Table 10) were extruded in ThermoFisher Process 11 twin screw extruder. The extrusion temperature in Table 10 indicates that all barrel temperature had 190 °C or 230 °C depending in each composition. The twin screw speed of the extruder and the single screw speed of the feeder are 60 RPM and 5 RPM, respectively. After extruded strands were cooled down in water bath and manually chopped. HomoPP pellets and BPS1 granules (or BPS2 powders) with or without thermoplastic elastomer pellets (or powders) are all hand-blended in the transparent plastic bags before feeding to the extruder. Total feeding amount is 2 kg and finally collected amount after the extrusion is 1.5 kg.

Table 10: Composition (wt%) of Practical and Comparative Examples in HomoPP Resin Containing BPS1 and BPS2										
Composition		1	2	3	4	5	6	7	8	9
Example type		Practical examples				Comparative examples				
Resins	homoPP	70	66	70	70	74	74	70	66	74
	BPS1	26	26	26		26	26	26	26	

Brominated flame retardant (brominated polystyrene type)	BPS2				26					26
Thermoplastic elastomer (Styrenic block copolymer)	SEBS (G1652)		8	4	4			4		
	SEBS-g-MAH (FG1901)	4								
	SEBS (A1535H)								8	
Extrusion temperature (°C)		230	230	230	190	190	230	190	230	190
Izod Impact (kJ/m ²) / ASTM D256		4.9±0.3	6.4±1.0	4.8±0.2	5.3±0.3	2.5±0.2	3.3±0.2	2.9±0.4	3.4±0.4	2.0±0.2
Impact Testing temperature (°C)		25 at 50 % relative humidity								

Table 11: Composition (wt%) of Practical and Comparative Examples in LLDPE Resin Containing BPS1							
Composition		10	11	12	13	14	15
Example type		Practical examples			Comparative examples		
Resins	LLDPE	69.5	69.5	69.5	74	74	69.5
Brominated flame retardant (brominated polystyrene type)	BPS1	23.1	23.1	23.1	26	26	23.1
Thermoplastic elastomer (Styrenic block copolymer)	SEBS-g-MAH (FG1901)		7.4				7.4
	SEBS (G1657)	7.4					
	SEPS (G1730)			7.4			
Extrusion temperature (°C)		230	230	230	230	185	185
Izod Impact (kJ/m ²) / ASTM D256		6.7±1.1	10.3±2.2	8.9±0.2	2.8±0.1	4.6±0.3	4.0±0.6
Impact Testing temperature (°C)		-37±1					

Table 12: Composition (wt%) of Practical and Comparative Examples in HomoPP Resin Containing EBP						
Composition		16	17	18	19	20
Example type		Practical examples			Comparative examples	
Resins	homoPP	82	80	80	90	80
Brominated flame retardant	EBP	10	10	10	10	10
Thermoplastic elastomer	HNBR (Zeon 1020L)	4	8			
	SEBS-g-MAH (FG1901)	4				
	TPU (Elastollan SP9339)			8		
	TPU (Elastollan 1195A)					8
Compatibilizer	PP-g-MAH (Polybond 3002)		2	2		2
Extrusion temperature (°C)		190	190	190	190	190
Izod Impact (kJ/m ²) / ASTM D256		6.7 ± 1.1	4.3 ± 0.3	4.5 ± 0.2	3.0±0.3	3.2±0.3
Impact Testing temperature (°C)		25 at 50 % relative humidity				

Table 13: Composition (wt%) of Practical and Comparative Examples in PS Resin Containing BPS1 or Ethylene-bis-tetrabromophthalimide					
Composition		21	22	23	24
Example type		Practical examples		Comparative examples	
Resins	Polystyrene	81	81	85	85
Brominated flame retardant	BPS1	15		15	
	Ethylene-bis-tetrabromophthalimide		15		15

Thermoplastic elastomer	SEBS-g-MAH (FG1901)	4	4		
Extrusion temperature (°C)		230	230	230	190
Critical stress intensity factor, K1c (MPa·m ^{-1/2}) / ASTM D5045		1.2±0.3	1.1±0.1	0.9±0.4	0.6±0.3
Testing temperature (°C)		25 at 50 % relative humidity			

Table 14: Composition (wt%) of Practical and Comparative Examples in HomoPP and coPP Resin Containing BPS1 and BPS2						
Composition		25	26	27	28	29
Example type		Practical examples		Comparative examples		
Resins	homoPP	47.7	47.7	53.7		53.7
	coPP1				53.7	
Brominated flame retardant (brominated polystyrene type)	BPS1	26.3		26.3	26.3	
	BPS2		26.3			26.3
Thermoplastic elastomer (Styrenic block copolymer)	SEBS-g-MAH (FG1901)	6	6			
Filler	ATO1	6	6	6	6	6
	talca	14	14	14	14	14
Total elastomer phase (%)		4.2	4.2	-	6.4	-
Processing condition		Direct compounding				
Izod Impact (kJ/m ²) / ASTM D256		3.8±0.1	5.2±0.6	2.0±0.5	2.1±0.1	1.7±0.3
Tensile strength (MPa) / ASTM D1708 (testing speed: 5 mm/min)		29.3±1.2	30.2±1.2	26±0.3	24.4±0.3	29.9±1.2
Elongation at break (%) / ASTM D1708 (testing speed: 5 mm/min)		60.6±25.6	105.5±46.5	15.7±1.8	14.5±2.6	8.9±2.0
Impact and tensile testing temperature (°C)		25 at 50 % relative humidity				

Table 15: Composition (wt%) of Practical and Comparative Examples in coPP Resin Containing BPS2 depending on processing condition								
Composition		30	31	32	33	34	35	36
Example type		Practical examples			Comparative examples			
Resins	coPP2	44.3	44.3	44.3	44.3	44.3	44.3	52.3

Brominated flame retardant (brominated polystyrene type)	BPS2	26.1	26.1	26.1	26.1	26.1	26.1	26.1
POE	Engage 8200	8			8			
	Engage 8407		8			8		
SEBS	A1535H			8			8	
Filler	ATO2	7.6	7.6	7.6	7.6	7.6	7.6	7.6
	talc	14	14	14	14	14	14	14
Processing condition		Consecutive compounding			Direct compounding			
Izod Impact (kJ/m ²) / ASTM D256		5.5±0.7	6.9±0.8	5.4±0.8	3.7±0.5	3.9±0.2	3.3±0.2	1.3±0.1
Tensile strength (MPa) / ASTM D1708 (testing speed: 50.8 mm/min)		16±0	16±0	18±0	16±0	16±0	16±0	19±0
Elongation at break (%) / ASTM D638 (testing speed: 50.8 mm/min)		4.9±1.1	3.8±2.2	7.7±1.9	4.7±0.9	3.3±0.6	3.0±0.5	1.7±0.2
Testing condition		23 °C at 50 % relative humidity						

Table 16: Composition (wt%) of Practical and Comparative Examples in coPP Resin Containing EBP						
Composition		37	38	39	40	41
Example type		Practical examples		Comparative examples		
Resins	coPP2	47.3	47.3	47.3	47.3	55.3
Brominated flame retardant	EBP	23.1	23.1	23.1	23.1	23.1
POE	Engage XLT 8677	8		8		
	Engage 8200		8		8	
Filler	ATO2	7.6	7.6	7.6	7.6	7.6
	talc	14	14	14	14	14
Processing condition		Consecutive compounding		Direct compounding		
Izod Impact (kJ/m ²) / ASTM D256		20.5±0.4	27.8±1.7	5.3±0.4	25.6±1.7	3.4±0.6
Tensile strength (MPa) / ASTM D638 (testing speed: 50.8 mm/min)		15±0	15±0	16±0	16±0	19±0
Elongation at break (%) / ASTM D638 (testing speed: 50.8 mm/min)		31.5±8.2	61.3±9.0	11.5±4.2	53.3±19.5	9.4±1.6

Testing condition	23 °C at 50 % relative humidity
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Table 17: Composition (wt%) of Practical and Comparative Examples in coPP Resin Containing BPS2 with SEBS								
Composition		42	43	44	45	46	47	36
Example type		Practical examples						Comparative examples
Resins	coPP2	44.3	44.3	44.3	44.3	44.3	44.3	52.3
Brominated flame retardant (brominated polystyrene type)	BPS2	26.1	26.1	26.1	26.1	26.1	26.1	26.1
SEBS	MD6951	8						
	G1642H		8					
	G1643V			8				
	MD1648				8			
	G1657V					8		
	G1645V						8	
Filler	ATO2	7.6	7.6	7.6	7.6	7.6	7.6	7.6
	talc	14	14	14	14	14	14	14
Processing condition		Direct compounding						
Izod Impact (kJ/m ²) / ASTM D256		4.0±0.3	10.2±0.5	8.9±0.6	6.9±0.4	10.1±0.6	8.7±0.4	1.3±0.1
Tensile strength (MPa) / ASTM D638 (testing speed: 50.8 mm/min)		16±0	16±0	16±0	17±0	14±0	16±0	19±0
Elongation at break (%) / ASTM D638 (testing speed: 50.8 mm/min)		9.4±3.5	30.0±8.6	23.7±6.0	20.4±1.4	12.6±2.1	27.7±1.3	1.7±0.2
Testing condition		23 °C at 50 % relative humidity						

Table 18: Composition (wt%) of Practical and Comparative Examples in coPP Resin Containing BPS2 with SBS or SEBS-g-MAH							
Composition	48	49	50	51	52	53	36
Example type	Practical examples					Comparative examples	

Resins	coPP2	44.3	44.3	44.3	44.3	44.3	52.3	52.3
Brominated flame retardant (brominated polystyrene type)	BPS1				26.1		26.1	
	BPS2	26.1	26.1	26.1		26.1		26.1
SBS	D1152E	8						
	D1116A		8					
SEBS-g-MAH	FG1901			8				
	FG1924G				8	8		
Filler	ATO2	7.6	7.6	7.6	7.6	7.6	7.6	7.6
	talc	14	14	14	14	14	14	14
Processing condition		Direct compounding						
Izod Impact (kJ/m ²) / ASTM D256		5.9±0.2	5.9±0.3	8.5±0.8	12.8±0.7	10.8±0.6	2.7±0.1	1.3±0.1
Tensile strength (MPa) / ASTM D1708 (testing speed: 50.8 mm/min)		15±0	14±0	15±0	13±0	14±0	18±0	19±0
Elongation at break (%) / ASTM D638 (testing speed: 50.8 mm/min)		14.3 ±1.1	13.7 ±	10.0±1.9	16.7 ±1.9	9.4±1.6	2.4±0.4	1.7±0.2
Testing condition		23 °C at 50 % relative humidity						
Table 19: Composition (wt%) of Practical and Comparative Examples in PPA Resin Containing BPS1								
Composition		54	55	56	57			
Example type		Practical examples					Comparative examples	
Resins	HTN-502	74	74	74	78			
Brominated flame retardant (brominated polystyrene type)	BPS1	22	22	22	22			
EMA-g-MAH	Lotader 4700T	4						
EMA-g-GMA	Lotader AX8930		4					
SEBS-g-GMA	02520 IM			4				
Processing condition		Consecutive compounding					Direct compounding	
Izod Impact (kJ/m ²) / ASTM D256		3.0±0.6	3.2±0.5	3.0±0.1	2.0±0.8			
Testing condition		23 °C at 50 % relative humidity						

[0121] Compositions in Tables 11 to 13 were compounded in Haake Rheocord (model 40) mixer for 7 mins for the formulations including EPB or BPS1 or ethylene-bis-tetrabromophthalimide. Total volumetric amount of one compounding batch is around 50 mL.

[0122] The sequence for the input of each ingredient into the mixing chamber is in the order of the resin, the brominated flame retardant next, the rubber next and then the compatibilizer. For example, in practical example 1, after melting homoPP completely, add EBP for 1 min, then add hydrogenated rubber for 30 s and then add SEBS-g-MAH rubber for 30 s. Total compounding time is 7 mins.

[0123] After 7 mins, open the chamber, collect the samples then chop them as the size of 5 mm × 5 mm × 2 mm.

[0124] Injection mold at barrel temperature of 190 °C and at the mold temperature of 60 °C. Cooling time is 10 s and the injection pressure is 670 bar. The molded bar has the size of 90 × 12.7 × 3.2 mm.

[0125] After machining the bar to the size of 63.5 × 12.7 × 3.2 mm having a 45° notch having depth of 2.54 mm at the center position, Izod impact and Plane strain critical stress intensity factor, K1c have been tested based on ASTM D256 and ASTM D5056 at the temperature of 25 °C or -37 °C.

[0126] Examples from composition 25 to composition 53 in Tables 14 to 18 were prepared by first compounding the raw materials in a Werner & Pfleider (Coperion) ZSK-30 twin-screw extruder (L/D 24, screw diameter 30 mm, barrel temperature 165 – 200 °C from hopper to die) with two feeders. Direct compounding means all materials were fed at one time. Pellets and granules were fed by one feeder and premixed powder fed by another feeder. The extrudate strands were chilled in ice water bath, air dried pelletized. Consecutive compounding means BPS and elastomeric polymers were extruded first with or without fillers. The first compounded materials were fed to second extrusion with matrix resins as Master Batches. The pellets were then injection molded into testing bars on a Boy 30A (35 ton) machine with a barrel temperature of 200 °C, injection pressure of 10 MPa and mold temperature of 35 °C, with a 15-second cooling time.

[0127] Examples from composition 54 to composition 57 (Table 19) were extruded in ThermoFisher Process 11 twin screw extruder with one feeder. The barrel temperature of the extruder is 285 to 320 °C from the hopper to the die. The twin screw speed was 150 RPM and feeding rate was 0.2 kg/h. Extruded strands were cool down in a conveying belt

then chopped by a pelletizer. PPA pellets and BPS1 granules with or without thermoplastic elastomer pellets (or powders) are all hand-blended in the transparent plastic bags before feeding to the extruder. Chopped pellets after extrusion were injection-molded via ThermoFisher Minijet pro for Izod bars under injection pressure: 3,450 psi, barrel temperature: 345 °C, mold temperature: 90 °C, and cooling time: 15 seconds. For consecutive compounding, admixed materials were prepared in the same way in Claim 126.

[0128]

TEM Observation

[0129] The block having 3 × 3 × 10 mm was cryogenically ultra-microtomed at the temperature of -120 °C by a diamond knife to get then TEM thin section (100 ~120 nm thickness) onto TEM copper grid (400 mesh size).

[0130] Each thin section on TEM copper grid was vapor-stained by 0.5% aqueous ruthenium tetroxide solution at ambient temperature for 10 mins to get the contrast difference between resin, rubber, and brominated FR.

[0131] Morphology was observed under JEOL 1200 EX or JEOL JEM-1400 at the electron beam voltage of 100 keV or 120 keV, respectively.

[0132] FIGs. 22A-22Q show TEM images of compositions from Tables 10-13 as follows: FIG. 22A shows composition 1, FIG. 22B shows composition 3, FIG. 22C shows composition 4, FIG. 22D shows composition 5, FIG. 22E shows composition 7, FIG. 22F shows composition 8, FIG. 22G shows composition 10, FIG. 22H shows composition 11, FIG. 22I shows composition 12, FIG. 22J shows composition 16, FIG. 22K shows composition 17, FIG. 22L shows composition 18, FIG. 22M shows composition 20, FIG. 22N shows composition 21, FIG. 22O shows composition 22, FIG. 22P shows composition 23, FIG. 22Q shows composition 24, FIG. 22R shows composition 25, FIG. 22S shows composition 26, FIG. 22T shows composition 31, FIG. 22U shows composition 34, FIG. 22V shows composition 48, FIG. 22X shows composition 52, FIG. 22Y shows composition 54, and FIG. 22Z shows composition 56 .

[0133] It should be emphasized that the above-described embodiments of the present disclosure are merely possible examples of implementations set forth for a clear understanding of the principles of the disclosure. Many variations and modifications may be made to the above-described embodiment(s) without departing substantially from the spirit and principles of the disclosure. All such modifications and variations are intended to be included herein within the scope of this disclosure and protected by the following claims.

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CLAIMS

What is claimed is:

1. A flame-retardant plastic composition comprising a polymeric component and a brominated flame retardant, wherein the brominated flame retardant comprises one or more particles at least partially encapsulated by a thermoplastic toughener.
2. The flame-retardant plastic composition of claim 1, wherein the polymeric component comprises polystyrene, low-density polyethylene (LDPE), linear low-density polyethylene (LLDPE), very-low-density polyethylene (VLDPE), ultra-low-density polyethylene (ULDPE), medium-density polyethylene (MDPE), polypropylene (PP), polymethylpentene (PMP), polybutene-1 (PB-1), ethylene-octene copolymer, stereo-block PP, olefin block copolymer, propylene-butane copolymer, polyisobutylene (PIB), poly(α -olefin), ethylene propylene rubber (EPR), ethylene propylene diene monomer rubber (EPDM rubber), high-density polyethylene (HDPE), ultra-high density polyethylene (UHDPE), a polyamide, a polyester, a styrenic polymer or copolymer, cross-linkable or cross-linked polyethylene (PEX or XLPE), or any combination thereof.
3. The flame-retardant plastic composition of claim 2, wherein the polyamide comprises nylon 6,6; nylon 6; nylon 6, 10; nylon 11; nylon 6,12; nylon 12; nylon 6,9; nylon 4,6; poly(m-phenylene isophthalamide); poly(p-phenylene terephthalamide); copoly(p-phenylene/d,4'-diphenyl ether terephthalamide); PA66/6, PA6T, PA9T, PA10T, PA4T, poly(m-xylene sebacamide), poly(m-xylene adipamide), a copolymer thereof, or any combination thereof.
4. The flame-retardant composition of claim 2, wherein the polyester comprises polyethylene terephthalate (PET), polytrimethylene terephthalate (PTT), polybutylene terephthalate (PBT), poly(cyclohexylenedimethylene terephthalate) (PCT), polylactic acid (PLA), polycaprolactone (PCL), polyethylene terephthalate glycol (PETG), polycyclohexylenedimethylene terephthalate glycol (PCTG), or any combination thereof.
5. The flame-retardant composition of claim 2, wherein the styrenic polymer or copolymer comprises poly(styrene-co-acrylonitrile) (SAN), poly(acrylonitrile-co-butadiene-styrene) (ABS), or any combination thereof.
6. The flame-retardant plastic composition of claim 1 or 2, wherein the polymeric component is selected from polypropylene, polystyrene, linear low-density polyethylene (LLDPE), or ethylene-1-octene copolymer.
7. The flame-retardant plastic composition of any one of claims 1-6, wherein the brominated flame retardant comprises 1,2-bis(pentabromophenyl)ethane, brominated polystyrene, ethylene-bis-tetrabromophthalimide, decabromodiphenyl oxide, brominated polystyrene;

poly(bromostyrene), polyvinyl bromide, polyvinylidene bromide, poly(2-bromoethyl methacrylate), poly(2,3-dibromopropyl methacrylate), poly(methyl- α -bromoacrylate), butadiene styrene brominated copolymer, or any combination thereof.

8. The flame-retardant plastic composition of any one of claims 1-7, wherein the thermoplastic toughener comprises a thermoplastic elastomer.

9. The flame-retardant plastic composition of any one of claims 1-8, wherein the thermoplastic toughener comprises a styrenic block copolymer, a thermoplastic polyurethane, a nitrile butadiene rubber, an acrylic elastomer, a copolyester elastomer, a thermoplastic polyether ester elastomer (TPEE), a thermoplastic amide ether elastomer (TAEE), a chlorinated rubber, an ionomer, a thermoplastic vulcanizate, or any combination thereof.

10. The flame-retardant plastic composition of claim 9, wherein the nitrile butadiene rubber comprises a hydrogenated nitrile butadiene rubber.

11. The flame-retardant plastic composition of claim 9, wherein the styrenic block copolymer comprises a styrene-ethylene butylene-styrene block copolymer (SEBS), a maleic anhydride grafted SEBS block copolymer, a styrene-ethylene propylene-styrene block copolymer (SEPS), or any combination thereof.

12. The flame-retardant plastic composition of claim 11, wherein the SEBS block copolymer has a styrene to ethylene and butylene ratio of from about 10:90 to about 70:30.

13. The flame-retardant plastic composition of claim 9, wherein the thermoplastic polyurethane comprises a polyester polyurethane, a polyether polyurethane, or any combination thereof.

14. The flame retardant plastic composition of claim 9, wherein the acrylic elastomer comprises ethylene acrylic terpolymer.

15. The flame retardant plastic composition of claim 9, wherein the chlorinated rubber comprises polychloroprene, a chloro polyethylene copolymer, or any combination thereof.

16. The flame retardant plastic composition of any one of claims 1-15, further comprising Sb_2O_3 .

17. The flame retardant plastic composition of claim 16, wherein the flame retardant plastic composition comprises from about 1% to about 10% by weight of Sb_2O_3 .

18. The flame-retardant plastic composition of any one of claims 1-17, further comprising a compatibilizer.

19. The flame-retardant plastic composition of claim 18, wherein the compatibilizer comprises a maleic anhydride grafted polypropylene.

20. The flame-retardant plastic composition of any one of claims 1-19, wherein the flame-retardant plastic composition comprises from about 65% to about 85% by weight of the polymeric component, from about 5% to about 35% by weight of the brominated flame retardant, from about 4% to about 8% by weight of the thermoplastic toughener, and from about 0% to about 2% by weight of the compatibilizer, based on a total weight of the polymeric component, the brominated flame retardant, the thermoplastic toughener, and the compatibilizer if present.

21. The flame-retardant plastic composition of any one of claims 1-20, further comprising a filler.

22. The flame-retardant plastic composition of claim 21, wherein the filler comprises talc, calcium carbonate, AgO, ZnO, CaO, MnO, Al(OH)₃, AlO(OH), Mg(OH)₂, kaolinite, wollastonite, mica, glass beads, or any combination thereof.

23. The flame-retardant plastic composition of any one of claims 1-22, wherein the one or more particles of the brominated flame retardant comprise (i) a plurality of particles individually partially encapsulated by the thermoplastic toughener, (ii) a plurality of particles individually fully encapsulated by the thermoplastic toughener, (iii) a plurality of clusters of two or more particles, wherein the individual clusters of the plurality are partially encapsulated as a group by the thermoplastic toughener, (iv) a plurality of clusters of two or more particles, wherein the individual clusters of the plurality are fully encapsulated as a group by the thermoplastic toughener, or (v) any combination thereof.

24. The flame-retardant plastic composition of any one of claims 1-23, wherein the one or more particles at least partially encapsulated by the thermoplastic toughener have a core-shell structure.

25. The flame-retardant plastic composition of any one of claims 24, wherein a shell layer of the core-shell structure has an average thickness of from about 5 nm to about 10 μ m.

26. The flame-retardant plastic composition of claim 25 wherein a ratio of the average thickness of the shell layer to an average length in at least one dimension of a core layer of the core-shell structure is from about 0.05:1 to about 1:1, most typically in the range from 0.05:1 to 0.25:1.

27. The flame-retardant plastic composition of any one of claims 1-26, wherein the flame-retardant plastic composition has a melt flow rate of about 7.5 to about 20 g/10 min.

28. An article comprising the flame-retardant plastic composition of any one of claims 1-27.

29. The article of any one of claim 28, wherein the article comprises an electronics component, an automotive component, insulation, carpeting, a wall covering, a coverings for a cables or a wire, a textile, an adhesive, or any combination thereof.

30. A method of making the flame-retardant plastic composition of any one of claims 1-29, the method comprising:

(a) admixing the polymeric component, the brominated flame retardant, and the thermoplastic toughener to form a precursor mixture; and

(b) extruding the precursor mixture at an elevated temperature.

31. The method of claim 30, wherein step (a), step (b), or both steps (a) and (b) are conducted in a twin screw extruder.

32. The method of claim 30 or 31, the elevated temperature is from about 160 °C to about 230 °C.

33. The method of claim 31 or 32, wherein the twin screw extruder has a speed of about 60 rpm.

34. The method of any one of claims 30-33, further comprising adding Sb_2O_3 during either step (a) or step (b).

35. A method of making the flame-retardant plastic composition of any one of claims 1-29, the method comprising admixing the polymeric component, the brominated flame retardant, the thermoplastic toughener, and optionally Sb_2O_3 in a double arm mixer.

36. A method of making the flame-retardant plastic composition of any one of claims 1-29, the method comprising:

(a) admixing the polymeric component and the brominated flame retardant to produce a Master Batch;

(b) admixing the Master Batch and the thermoplastic toughener to form a second mixture; and

(c) extruding the second mixture at an elevated temperature.

37. The method of claim 36, wherein one or more of step (a), step (b), and step (c) are carried out in a twin screw extruder.

38. The method of claim 36 or 37, wherein the elevated temperature is from about 160 °C to about 230 °C.

39. The method of any one of claims 36-38, wherein the twin screw extruder has a speed of about 60 rpm.

40. The method of any one of claims 36-39, further comprising adding Sb_2O_3 during either step (a) or step (b).