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(54) Title: BLOCK COPOLYMERS HAVING HIGH FLOW AND HIGH ELASTICITY

(57) Abstract: Disclosed is an elastomeric hydrogenated block copolymer capable of being directly extruded or molded with a minimum of additives and having both high elasticity and low permanent set. The hydrogenated block copolymers have high melt flows allowing for ease in processing the hydrogenation block copolymers in melt processes such as extrusion and molding.



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## **Block Copolymers Having High Flow and High Elasticity**

### **CROSS-REFERENCE TO RELATED APPLICATION**

The present application claims the benefit of U.S. Provisional patent  
5 application 60/549,570, filed March 3, 2004, entitled Block Copolymers Having High Flow and High Elasticity.

### **BACKGROUND OF THE INVENTION**

#### **1. Field of the Invention**

10 This invention relates to hydrogenated anionic block copolymers of mono alkenyl arenes and conjugated dienes, and to articles made from such block copolymers. This invention particularly relates to hydrogenated block copolymers of styrene and butadiene or isoprene.

#### **2. Background of the Art**

The preparation of block copolymers of mono alkenyl arenes and conjugated dienes is well known. One of the first patents on linear ABA block copolymers made with styrene and butadiene is U.S. Patent No. 3,149,182. Uses for the block copolymers include injection molding, extrusion, blow molding,  
20 adhesives, and the like. These polymers have also been used in applications such as the modification of bitumen for the production of roofs and roads. Other uses of block copolymers include the production of films, fibers, and non-woven fabrics.

25 One example of such a block copolymer is in U. S. Patent No. 4,188,432 to Holden, et al. Disclosed therein are shaped articles which are resistant to attack by fatty substances consisting essentially of high impact styrene-butadiene graft copolymer or a mixture thereof with no more than about 55% styrene homopolymer. The shaped articles also include small proportions of  
30 polyethylene or polypropylene and of a block copolymer X-Y-X in which each X is a polystyrene block of about 5,000 to 10,000 molecular weight and Y is a hydrogenated polybutadiene block of 25,000 to 50,000 molecular weight.

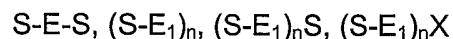
Another example of a block copolymer is found in U.S. Patent No. 5,705,556 to Djiauw, et al. In this reference, it is disclosed that an extrudable elastomeric composition for making elastic fibers or films can be prepared using an elastomeric block copolymer, a polyphenylene ether, a polyolefin, and a tackifying resin. The article is further described as having from 25% to 75% by weight of a block copolymer having at least two monoalkenyl arene blocks separated by a hydrogenated conjugated diene block.

It is known in the art of preparing articles from polymers using injection molding, extrusion, and fiber spinning to use processing aids to reduce undesirable properties of the polymer being used. For example, fiber lubricants having excellent stability to smoking under conditions of use at elevated temperature in the mechanical and heat treatment operation subsequent to extrusion of the fiber, is disclosed in U.S. Patent Pat. No. 4,273,946 to Newkirk, et al.

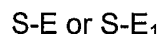
The above referenced block copolymer and today's other conventional highly elastic block copolymers, while having many desirable properties, can be difficult to process, particularly in extrusion, molding and fiber spinning applications. For example, it is commonly practiced to use substantial amounts of polyolefins, extending oils, tackifying resin and waxes and/or other processing aids in order to extrude conventional block copolymers. These additives can be difficult to add, often lead to reductions in elastic properties and can cause undesirable processing problems such as smoking and die buildup. On the other hand, conventional block copolymers can be made with good processability, however their mechanical properties are so poor that they are not generally useful in molded and extruded articles. It would be desirable in the art of preparing molded, extruded, and spun articles from block copolymers to prepare such articles using a block copolymer that does not require as much or even any processing aids and yet has excellent elastic properties.

**SUMMARY OF THE INVENTION**

In one aspect, the present invention is a selectively hydrogenated block copolymer having an S block and an E or E<sub>1</sub> block and having the general  
 5 formula:

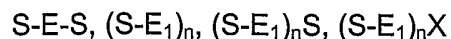


or mixtures thereof, wherein: (a) prior to hydrogenation the S block is a polystyrene block; (b) prior to hydrogenation the E block is a polydiene block, selected from the group consisting of polybutadiene, polyisoprene and  
 10 mixtures thereof, having a molecular weight of from 40,000 to 70,000; (c) prior to hydrogenation the E<sub>1</sub> block is a polydiene block, selected from the group consisting of polybutadiene, polyisoprene and mixtures thereof, having a molecular weight of from 20,000 to 35,000; (d) n has a value of 2 to 6 and X is a coupling agent residue; (e) the styrene content of the block copolymer is  
 15 from 13 percent to 25 percent; (f) the vinyl content of the polydiene block prior to hydrogenation is from 60 to 85 mol percent; (g) the block copolymer includes less than 15 weight percent lower molecular weight units having the general formula:

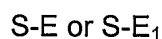


20 wherein S, E and E<sub>1</sub> are as already defined; (h) subsequent to hydrogenation about 0-10% of the styrene double bonds have been hydrogenated and at least 80% of the conjugated diene double bonds have been hydrogenated; (i) the molecular weight of each of the S blocks is from 5,000 to 7,000; and (j) the melt index of the block copolymer is greater than or equal to 12 grams/10  
 25 minutes according to ASTM D1238 at 230°C and 2.16 kg weight.

In still another aspect, the present invention is an article selected from the group consisting of a: film, sheet, coating, band, strip, profile, tube, molding, foam, tape, fabric, thread, filament, ribbon, fiber, plurality of fibers and fibrous  
 30 web; wherein the article is prepared using a selectively hydrogenated block copolymer having an S block and an E or E<sub>1</sub> block and having the general formula:

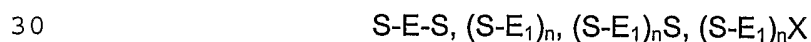


or mixtures thereof, wherein: (a) prior to hydrogenation the S block is a polystyrene block; (b) prior to hydrogenation the E block is a polydiene block, selected from the group consisting of polybutadiene, polyisoprene and mixtures thereof, having a molecular weight of from 40,000 to 70,000; (c) prior to hydrogenation the E<sub>1</sub> block is a polydiene block, selected from the group consisting of polybutadiene, polyisoprene and mixtures thereof, having a molecular weight of from 20,000 to 35,000; (d) n has a value of 2 to 6 and X is a coupling agent residue; (e) the styrene content of the block copolymer is from 13 percent to 25 percent; (f) the vinyl content of the polydiene block prior to hydrogenation is from 60 to 85 mol percent; (g) the block copolymer includes less than 15 weight percent lower molecular weight units having the general formula:



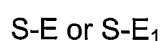
wherein S, E and E<sub>1</sub> are as already defined; (h) subsequent to hydrogenation about 0-10% of the styrene double bonds have been hydrogenated and at least 80% of the conjugated diene double bonds have been hydrogenated; (i) the molecular weight of each of the S blocks is from 5,000 to 7,000 and (j) the melt index of the block copolymer is greater than or equal to 12 grams/10 minutes according to ASTM D1238 at 230°C and 2.16 kg weight.

Another aspect of the present invention is an article selected from the group consisting of a film, tape, tube, strip, fiber, or filament made by direct extrusion capable of being used alone or in a laminate structure with a plurality of other layers; or a transparent, flexible part prepared by process selected from the group consisting of injection molding, slush molding, rotational molding, compression molding, and dipping; wherein the article is prepared using a selectively hydrogenated block copolymer having an S block and an E or E<sub>1</sub> block and having the general formula:



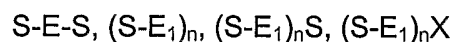
or mixtures thereof, wherein: (a) prior to hydrogenation the S block is a polystyrene block; (b) prior to hydrogenation the E block is a polydiene block,

selected from the group consisting of polybutadiene, polyisoprene and mixtures thereof, having a molecular weight of from 40,000 to 70,000; (c) prior to hydrogenation the  $E_1$  block is a polydiene block, selected from the group consisting of polybutadiene, polyisoprene and mixtures thereof, having a  
 5 molecular weight of from 20,000 to 35,000; (d)  $n$  has a value of 2 to 6 and  $X$  is a coupling agent residue; (e) the styrene content of the block copolymer is from 13 percent to 25 percent; (f) the vinyl content of the polydiene block prior to hydrogenation is from 60 to 85 mol percent; (g) the block copolymer includes less than 15 weight percent lower molecular weight units having the  
 10 general formula:



wherein  $S$ ,  $E$  and  $E_1$  are as already defined; (h) subsequent to hydrogenation about 0-10% of the styrene double bonds have been hydrogenated and at least 80% of the conjugated diene double bonds have been hydrogenated; (i)  
 15 the molecular weight of each of the  $S$  blocks is from 5,000 to 7,000; and wherein the hydrogenated block copolymer has a melt index greater than 50 and the hysteresis recovery is greater than 60%.

In still another aspect, the present invention is a block copolymer having an  $S$   
 20 block and an  $E$  or  $E_1$  block and having the general formula:



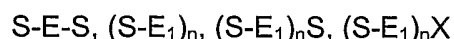
or mixtures thereof, wherein: (a) the  $S$  block is a polystyrene block; (b) the  $E$  block is a polydiene block, selected from the group consisting of polybutadiene, polyisoprene and mixtures thereof, having a molecular weight  
 25 of from 40,000 to 70,000; (c) the  $E_1$  block is a polydiene block, selected from the group consisting of polybutadiene, polyisoprene and mixtures thereof, having a molecular weight of from 20,000 to 35,000; (d)  $n$  has a value of 2 to 6 and  $X$  is a coupling agent residue; (e) the styrene content of the block copolymer is from 13 percent to 25 percent; (f) the vinyl content of the  
 30 polydiene block prior to hydrogenation is from 60 to 85 mol percent; (g) the block copolymer includes less than 15 weight percent lower molecular weight units having the general formula:

S-E or S-E<sub>1</sub>

wherein S, E and E<sub>1</sub> are as already defined; and (h) the molecular weight of each of the S blocks is from 5,000 to 7,000.

### **DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS**

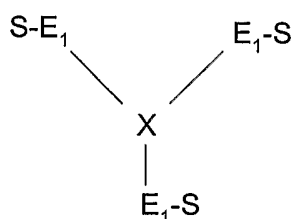
- 5 In one embodiment, the present invention is a selectively hydrogenated block copolymer having an S block and an E or E<sub>1</sub> block and having the general formula:



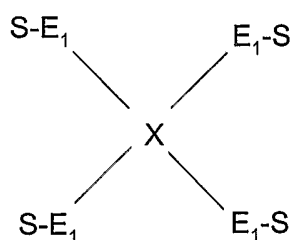
- or mixtures thereof, wherein: (a) prior to hydrogenation, the S block is a polystyrene block; (b) prior to hydrogenation, the E block or E<sub>1</sub> block is a polydiene block, selected from the group consisting of polybutadiene, polyisoprene and mixtures thereof. The block copolymer can be linear or radial having three to six arms. General formulae for the linear configurations include:

- 15 S-E-S and/or (S-E<sub>1</sub>)<sub>n</sub> and/or (S-E<sub>1</sub>)<sub>n</sub>S

- wherein the E block is a polydiene block, selected from the group consisting of polybutadiene, polyisoprene and mixtures thereof, having a molecular weight of from 40,000 to 70,000; the E<sub>1</sub> block is a polydiene block, selected from the group consisting of polybutadiene, polyisoprene and mixtures thereof, having a molecular weight of from 20,000 to 35,000; and n has a value from 2 to 6, preferably from 2 to 4, and more preferably an average of approximately 3. General formula for the radial configurations include:



and



wherein the E<sub>1</sub> block is a polydiene block, selected from the group consisting of polybutadiene, polyisoprene and mixtures thereof, having a molecular weight of from 20,000 to 35,000; and X is a coupling agent  
 5 residue.

As used herein, the term "molecular weights" refers to the true molecular weight in g/mol of the polymer or block of the copolymer. The molecular weights referred to in this specification and claims can be measured with  
 10 gel permeation chromatography (GPC) using polystyrene calibration standards, such as is done according to ASTM 3536. GPC is a well-known method wherein polymers are separated according to molecular size, the largest molecule eluting first. The chromatograph is calibrated using commercially available polystyrene molecular weight standards. The  
 15 molecular weight of polymers measured using GPC so calibrated are styrene equivalent molecular weights. The styrene equivalent molecular weight may be converted to true molecular weight when the styrene content of the polymer and the vinyl content of the diene segments are known. The detector used is preferably a combination ultraviolet and refractive index  
 20 detector. The molecular weights expressed herein are measured at the peak of the GPC trace, converted to true molecular weights, and are commonly referred to as "peak molecular weights".

The block copolymers of the present invention are prepared by anionic  
 25 polymerization of styrene and a diene selected from the group consisting of butadiene, isoprene and mixtures thereof. The polymerization is accomplished by contacting the styrene and diene monomers with an organoalkali metal

compound in a suitable solvent at a temperature within the range from about -150°C to about 300°C, preferably at a temperature within the range from about 0°C to about 100°C. Particularly effective anionic polymerization initiators are organolithium compounds having the general formula  $RLi_n$  where R is an aliphatic, cycloaliphatic, aromatic, or alkyl-substituted aromatic hydrocarbon radical having from 1 to 20 carbon atoms; and n has a value from 1 to 4. Preferred initiators include n-butyl lithium and sec-butyl lithium. Methods for anionic polymerization are well known and can be found in such references as U.S. Patent Nos. 4,039,593 and U.S. Reissue Patent No. Re 27,145.

10

The block copolymers of the present invention can be linear, linear coupled, or a radial block copolymer having a mixture of 2 to 6 "arms". Linear block copolymers can be made by polymerizing styrene to form a first S block, adding butadiene to form an E block, and then adding additional styrene to form a second S block. A linear coupled block copolymer is made by forming the first S block and E block and then contacting the diblock with a difunctional coupling agent. A radial block copolymer is prepared by using a coupling agent that is at least trifunctional.

20 Difunctional coupling agents useful for preparing linear block copolymers include, for example, methyl benzoate as disclosed in U. S. Patent No. 3,766,301. Other coupling agents having two, three or four functional groups useful for forming radial block copolymers include, for example, silicon tetrachloride and alkoxy silanes as disclosed in U. S. Patent Nos. 3,244,664, 3,692,874, 4,076,915, 5,075,377, 5,272,214 and 5,681,895; polyepoxides, polyisocyanates, polyimines, polyaldehydes, polyketones, polyanhydrides, polyesters, polyhalides as disclosed in U. S. Patent No. 3,281,383; diesters as disclosed in U.S. Patent No. 3,594,452; methoxy silanes as disclosed in U.S. Patent No. 3,880,954; divinyl benzene as disclosed in U.S. 3,985,830; 1,3,5-benzenetricarboxylic acid trichloride as disclosed in U.S. Patent No. 4,104,332; glycidoxytrimethoxy silanes as disclosed in U.S. Patent No. 4,185,042; and oxydipropylbis(trimethoxy silane) as disclosed in U.S. Patent No. 4,379,891.

30

In one embodiment of the present invention, the coupling agent used is an alkoxy silane of the general formula  $R_x-Si-(OR')_y$ , where  $x$  is 0 or 1,  $x + y = 3$  or 4,  $R$  and  $R'$  are the same or different,  $R$  is selected from aryl, linear alkyl and  
5 branched alkyl hydrocarbon radicals, and  $R'$  is selected from linear and branched alkyl hydrocarbon radicals. The aryl radicals preferably have from 6 to 12 carbon atoms. The alkyl radicals preferably have 1 to 12 carbon atoms, more preferably from 1 to 4 carbon atoms. Under melt conditions these alkoxy silane coupling agents can couple further to yield functionalities greater than 4.  
10 Preferred tetra alkoxy silanes are tetramethoxy silane ("TMSi"), tetraethoxy silane ("TESi"), tetrabutoxy silane ("TBSi"), and tetrakis(2-ethylhexyloxy)silane ("TEHSi"). Preferred trialkoxy silanes are methyl trimethoxy silane ("MTMS"), methyl triethoxy silane ("MTES"), isobutyl trimethoxy silane ("IBTMO") and phenyl trimethoxy silane ("PhTMO"). Of these the more preferred are  
15 tetraethoxy silane and methyl trimethoxy silane.

One important aspect of the present invention is the microstructure of the polymer. The microstructure relevant to the present invention is a high amount of vinyl in the E and/or  $E_1$  blocks. This configuration can be achieved by the  
20 use of a control agent during polymerization of the diene. A typical agent is diethyl ether. See U.S. Patent No. Re 27,145 and U.S. Patent No. 5,777,031, the disclosure of which is hereby incorporated by reference. Any microstructure control agent known to those of ordinary skill in the art of preparing block copolymers to be useful can be used to prepare the block  
25 copolymers of the present invention.

In the practice of the present invention, the block copolymers are prepared so that they have from about 60 to about 85 mol percent vinyl in the E and/or  $E_1$  blocks prior to hydrogenation. In another embodiment, the block copolymers  
30 are prepared so that they have from about 65 to about 85 mol percent vinyl content. In still another embodiment, the block copolymers are prepared so that they have from about 70 to about 85 mol percent vinyl content. Another

embodiment of the present invention includes block copolymers prepared so that they have from about 73 to about 83 mol percent vinyl content in the E and/or E<sub>1</sub> blocks.

5 In one embodiment, the present invention is a hydrogenated block copolymer. The hydrogenated block copolymers of the present invention are selectively hydrogenated using any of the several hydrogenation processes known in the art. For example, the hydrogenation may be accomplished using methods such as those taught, for example, in U.S. Patent Nos. 3,494,942; 3,634,594;  
10 3,670,054; 3,700,633; and Re. 27,145, the disclosures of which are hereby incorporated by reference. Any hydrogenation method that is selective for the double bonds in the conjugated polydiene blocks, leaving the aromatic unsaturation in the polystyrene blocks substantially intact, can be used to prepare the hydrogenated block copolymers of the present invention.

15

The methods known in the prior art and useful for preparing the hydrogenated block copolymers of the present invention involve the use of a suitable catalyst, particularly a catalyst or catalyst precursor comprising an iron group metal atom, particularly nickel or cobalt, and a suitable reducing agent such as  
20 an aluminum alkyl. Also useful are titanium based catalyst systems. In general, the hydrogenation can be accomplished in a suitable solvent at a temperature within the range from about 20°C to about 100°C, and at a hydrogen partial pressure within the range from about 100 psig (689 kPa) to about 5,000 psig (34,473 kPa). Catalyst concentrations within the range from about 10 ppm to  
25 about 500 ppm by wt of iron group metal based on total solution are generally used and contacting at hydrogenation conditions is generally continued for a period of time with the range from about 60 to about 240 minutes. After the hydrogenation is completed, the hydrogenation catalyst and catalyst residue will, generally, be separated from the polymer.

30

In the practice of the present invention, the hydrogenated block copolymers have a hydrogenation degree greater than 80 percent. This means that more

than from 80 percent of the conjugated diene double bonds in the E or E<sub>1</sub> block has been hydrogenated from an alkene to an alkane. In one embodiment, the E or E<sub>1</sub> block has a hydrogenation degree greater than about 90 percent. In another embodiment, the E or E<sub>1</sub> block has a hydrogenation  
5 degree greater than about 95 percent.

In the practice of the present invention, the styrene content of the block copolymer is from about 13 percent to about 25 weight percent. In one embodiment, the styrene content of the block copolymer is from about 15  
10 percent to about 24 percent. Any styrene content within these ranges can be used with the present invention. Subsequent to hydrogenation, from 0 to 10 percent of the styrene double bonds in the S blocks have been hydrogenated in the practice of the present invention.

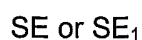
15 The molecular weight of each of the S blocks in the block copolymers of the present invention is from about 5,000 to about 7,000 in the block copolymers of the present invention. In one embodiment, the molecular weight of each of the S blocks is from about 5,800 to about 6,600. The S blocks of the block copolymers of the present invention can be a polystyrene block having any  
20 molecular weight within these ranges.

In the practice of the present invention, the E blocks are a single polydiene block. These polydiene blocks can have molecular weights that range from about 40,000 to about 70,000. The E<sub>1</sub> block is a polydiene block having a  
25 molecular weight range of from about 20,000 to about 35,000. In one embodiment, the molecular weight range of the E block is from about 45,000 to about 60,000, and the molecular weight range for each E<sub>1</sub> block of a coupled block copolymer, prior to being coupled, is from about 22,500 to about 30,000

30

One advantage of the present invention over conventional hydrogenated block copolymer is that they have high melt flows that allow them to be easily

molded or continuously extruded into shapes or films or spun into fibers. This property allows end users to avoid or at least limit the use of additives that degrade properties, cause area contamination, smoking, and even build up on molds and dies. But the hydrogenated block copolymers of the present invention also are very low in contaminants that can cause these undesirable effects, such as diblocks from inefficient coupling. The block copolymers and hydrogenated block copolymers of the present invention have less than 15 weight percent of diblock content, such diblocks having the general formula:



wherein S, E and  $E_1$  are as previously defined. In one embodiment, the diblock level is less than 10 percent in another embodiment less than 8 percent. For example, where the structure of the hydrogenated block copolymer is  $(S-E_1)_2X$ , the block copolymer contains less than 10% of the  $S-E_1$  species. All percentages are by weight.

15

One characteristic of the hydrogenated block copolymers of the present invention is that they have a low order-disorder temperature. The order-disorder temperature (ODT) of the hydrogenated block copolymers of the present invention is typically less than about 250°C. Above 250°C the polymer is more difficult to process although in certain instances for some applications ODT's greater than 250°C can be utilized. One such instance is when the block copolymer is combined with other components to improve processing. Such other components may be thermoplastic polymers, oils, resins, waxes or the like. In one embodiment, the ODT is less than about 240°C. Preferably, the hydrogenated block copolymers of the present invention have an ODT of from about 210°C to about 240°C. This property can be important in some applications because when the ODT is below 210°C, the block copolymer may exhibit creep that is undesirably excessive or low strength. For purposes of the present invention, the order-disorder temperature is defined as the temperature above which a zero shear viscosity can be measured by capillary rheology or dynamic rheology.

30

For the purposes of the present invention, the term "melt index" is a measure of the melt flow of the polymer according ASTM D1238 at 230°C and 2.16 kg weight. It is expressed in units of grams of polymer passing through a melt rheometer orifice in 10 minutes. The hydrogenated block copolymers of the present invention have a desirable high melt index allowing for easier processing than similar hydrogenated block copolymers that have higher melt indexes. In one embodiment, the hydrogenated block copolymers of the present invention have a melt index of greater than or equal to 12. In another embodiment, the hydrogenated block copolymers of the present invention have a melt index of greater than or equal to 20. In still another embodiment, the hydrogenated block copolymers of the present invention have a melt index of greater than or equal to 40. Another embodiment of the present invention includes hydrogenated block copolymers having a melt index of from about 20 to about 100. Still another embodiment of the present invention includes hydrogenated block copolymers having a melt index of from about 50 to about 85.

The hydrogenated block copolymers of the present invention are especially suited for use in preparing articles requiring a melt based processing. For example, the hydrogenated block copolymers of the present invention can be used in a process selected from the group consisting of injection molding, over molding, insert molding, dipping, extrusion, roto molding, slush molding, fiber spinning, film making, and foaming. Articles made using such processes include: film, sheet, coating, band, strip, profile, tube, molding, foam, tape, fabric, thread, filament, ribbon, fiber, plurality of fibers, fibrous web and laminates containing a plurality of film and or fiber layers.

While the hydrogenated copolymers of the present invention have such low order-disorder temperatures and high melt indexes that they can be used to prepare articles without using processing aids, it is sometimes desirable to use such aids and other additives. Exemplary of such additives are members selected from the group consisting of other block copolymers, olefin polymers,

styrene polymers, tackifying resins, end block resins, polymer extending oils, waxes, fillers, reinforcements, lubricants, stabilizers, engineering thermoplastic resins, and mixtures thereof.

- 5 When the additive is an olefin polymer, exemplary polymers include, for example, ethylene homopolymers, ethylene/alpha-olefin copolymers, propylene homopolymers, propylene/alpha-olefin copolymers, high impact polypropylene, butylene homopolymers, butylene/alpha olefin copolymers, and other alpha olefin copolymers or interpolymers. Representative polyolefins  
10 include, for example, but are not limited to, substantially linear ethylene polymers, homogeneously branched linear ethylene polymers, heterogeneously branched linear ethylene polymers, including linear low density polyethylene (LLDPE), ultra or very low density polyethylene (ULDPE or VLDPE), medium density polyethylene (MDPE), high density polyethylene  
15 (HDPE) and high pressure low density polyethylene (LDPE). Other polymers included hereunder are ethylene/acrylic acid (EAA) copolymers, ethylene/methacrylic acid (EMAA) ionomers, ethylene/vinyl acetate (EVA) copolymers, ethylene/vinyl alcohol (EVOH) copolymers, ethylene/cyclic olefin copolymers, polypropylene homopolymers and copolymers, propylene/styrene  
20 copolymers, ethylene/propylene copolymers, polybutylene, ethylene carbon monoxide interpolymers (for example, ethylene/carbon monoxide (ECO) copolymer, ethylene/acrylic acid/carbon monoxide terpolymer and the like. Preferred are high clarity, soft olefin polymers such as polyethylene and polypropylene copolymers, plastomers, elastomers and interpolymers.  
25 Examples include Affinity, Engage and Versify polymers from Dow Chemical and Exact and Vistamaxx polymers from Exxon Mobil. Still other polymers included hereunder are polyvinyl chloride (PVC) and blends of PVC with other materials.
- 30 The hydrogenated copolymers of the present invention can also be admixed with styrene polymers. Styrene polymers include, for example, crystal polystyrene, high impact polystyrene, medium impact polystyrene,

styrene/acrylonitrile copolymers, styrene/acrylonitrile/butadiene (ABS) polymers, syndiotactic polystyrene and styrene/olefin copolymers. Representative styrene/olefin copolymers are substantially random ethylene/styrene or propylene/styrene copolymers, preferably containing at least 20 weight percent copolymerized styrene monomer. Also included are styrene-grafted polypropylene polymers, such as those offered under the trade name Interloy®, originally developed by Himont, Inc. (now Basell). The hydrogenated copolymers of the present invention can also be admixed with other block copolymers such as styrene-diene-styrene triblock, radial or star block polymers, styrene-diene diblock polymers, and the hydrogenated versions of these polymers. . Examples of high vinyl polymers which may be used include Hybrar® from Kurraray and Dynaron from JSR.

For the purposes of the specification and claims of the present invention, the term "engineering thermoplastic resin" encompasses the various polymers found in the classes listed in Table A below, and further defined in US Patent No. 4,107,131, the disclosure of which is hereby incorporated by reference.

**Table A**

Thermoplastic Polyester
Thermoplastic Polyurethane
Poly(aryl ether) and Poly(aryl sulfone)
Polycarbonate
Acetal resin
Polyamide
Halogenated thermoplastic
Nitrile barrier resin
Poly(methyl methacrylate)
Cyclic olefin copolymers

When the additives used with the hydrogenated block copolymers of the present invention are tackifying resins, exemplary resins include polystyrene block compatible resins and midblock compatible resins. The polystyrene block compatible resin may be selected from the group of coumarone-indene resin, polyindene resin, poly(methyl indene) resin, polystyrene resin, vinyltoluene-  
5 alphas-methylstyrene resin, alphas-methylstyrene resin and polyphenylene ether, in particular poly(2,6-dimethyl-1,4-phenylene ether). Such resins are e.g. sold under the trademarks "HERCURES", "ENDEX", "KRISTALEX", "NEVCHEM" and "PICCOTEX". Resins compatible with the hydrogenated (mid) block may  
10 be selected from the group consisting of compatible C5 hydrocarbon resins, hydrogenated C5 hydrocarbon resins, styrenated C5 resins, C5/C9 resins, styrenated terpene resins, fully hydrogenated or partially hydrogenated C9 hydrocarbon resins, rosins esters, rosins derivatives and mixtures thereof. These resins are e.g. sold under the trademarks "REGALITE", "REGALREZ",  
15 "ESCOREZ" and "ARKON". Also, one may use both a polystyrene block compatible resin and a midblock compatible resin.

When additives are elastomeric polyethylene or polypropylene copolymers, examples include Affinity, Engage and Versify polymers from Dow Chemical  
20 and Exact and Vistamaxx polymers from Exxon Mobil.

While the above referenced additives can be used, it is often desirable to limit their use to avoid problems inherent therewith including but not limited to smoking, die build up, mold build up, area contamination, and the like. In one  
25 embodiment, the total concentration of additives present in an article prepared with a hydrogenated block copolymer of the present invention is from about 0.001 percent to about 25 percent by weight. In another embodiment the total concentration of additives present in an article prepared with a hydrogenated block copolymer of the present invention is from about 0.001 percent to about  
30 10 percent by weight. In still another embodiment the total concentration of additives present in an article prepared with a hydrogenated block copolymer of the present invention is from about 0.001 percent to about 5 percent by

weight. Another embodiment of the present invention includes one where the total concentration of additives present in an article prepared with a hydrogenated block copolymer of the present invention is from about 0.001 percent to about 1 percent by weight.

5

The polymer of the present invention may be used in a large number of applications, either as a neat polymer or in a compound. The following various end uses and/or processes are meant to be illustrative, and not limiting to the present invention:

- 10 • Polymer modification applications
- Injection molding of toys, medical devices
- Extruding films, tubing, profiles
- Over molding applications for personal care, grips, soft touch applications, for automotive parts, such as airbags, steering wheels, etc
- 15 • Dipped goods, such as gloves
- Thermoset applications, such as in sheet molding compounds or bulk molding compounds for trays
- Roto molding for toys and other articles
- Slush molding of automotive skins
- 20 • Thermal spraying for coatings
- Blown film for medical devices
- Hot melt adhesive
- Blow molding for automotive/industrial parts
- Films and fibers for personal hygiene applications
- 25 • Tie layer for functionalized polymers
- Roofing sheets
- Geomembrane applications

The hydrogenated block copolymers of the present invention have very elastic properties and yet also very high melt indexes. In one embodiment, the hydrogenated block copolymers of the present invention have a hysteresis

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recovery of greater than 50 percent and a permanent set of less than 20 percent on the first retraction cycle after elongation to 300 percent. For example, a preferred embodiment of the present invention is hydrogenated block copolymer having a melt index of greater than 50 and a hysteresis recovery of greater than 60 percent. This embodiment is particularly useful for preparing an article selected from the group consisting of a film, tape, tube, strip, fiber, or filament made by direct extrusion capable of being used alone or in a laminate structure with a plurality of other layers; or a transparent, flexible part prepared by process selected from the group consisting of injection molding, slush molding, rotational molding, compression molding, and dipping.

These articles can be prepared, optionally including from 0.001 percent to 10 percent by weight of additives to enhance flow, stiffness or elasticity selected from a group including stabilizers, extender oil, waxes, tackifying resins, end block resins, surface modifiers and polyolefins. When present, the additive or additives can include a polyethylene or polypropylene homopolymer or copolymer. In one embodiment the polyethylene or polypropylene homopolymer or copolymer is a high clarity polypropylene copolymer that can be a polyethylene or polypropylene plastomer, elastomer or interpolymers.

20

### **EXAMPLES**

The following examples are provided to illustrate the present invention. The examples are not intended to limit the scope of the present invention and they should not be so interpreted. Amounts are in weight parts or weight percentages unless otherwise indicated.

25

#### **Example 1**

A hydrogenated block copolymer is prepared by anionic polymerization of styrene and then butadiene in the presence of a microstructure control agent followed by coupling and then hydrogenation: a diblock polymer anion, S-B-Li, is prepared by charging 361 kg of cyclohexane and 16.7 kg, of styrene to a reactor. The reactor temperature was increased to about 40°C. Impurities

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were removed by adding small aliquots of s-butyllithium until the first evidence of color. 1,900 milliliters of a solution of an approximately 12%wt solution of s-butyllithium in cyclohexane was added, and the styrene was allowed to complete polymerization at about 60°C. The molecular weight of the polystyrene produced in this reaction was determined to be 6,400 by GPC. 320 g. of 1,2 – diethoxypropane were added, and then 72.6 kg of butadiene were added at rates to allow the temperature to remain about 60°C. A sample collected at the end of the butadiene polymerization had a styrene content of 21.3%wt and a vinyl content of 69% basis <sup>1</sup>H NMR and an overall molecular weight of 35,000 as determined by GPC. Following polymerization of the majority of the butadiene, 623 g. of isoprene was added. The isoprene was allowed to polymerize, and then 257 g of TESi was added, and the coupling reaction was allowed to proceed for 60 minutes at 60°C. Methanol (8.5 g, 0.1 mol per mol of Li) was added to terminate the reaction. The final product had a coupling efficiency of 91% and 72% of the coupled species were linear with the remaining 28 percent being 3-arm radial.

A sample of the polymer was hydrogenated to a residual olefin concentration of 0.09 meq/g in the presence of 20 ppm as [Co] of a solution of cobalt neodecanoate-aluminum triethyl catalyst (Al/Co = 1.7 mol/mol). After hydrogenation under these conditions, the polymer remained 91% coupled. The catalyst was removed by washing with aqueous phosphoric acid, and the polymer was recovered via steam stripping, under conditions typical for hydrogenated polymers.

Samples were taken such that the molecular weight of the styrene block and butadiene/isoprene blocks could be determined. The amount of butadiene in the 1,2 configuration before hydrogenation and the coupling efficiency was also determined. The hydrogenated block copolymer was tested for melt flow and ODT. The results of the testing are displayed below in Table 1.

## Example 2

A hydrogenated block copolymer was prepared by anionic polymerization of styrene and then butadiene in the presence of a microstructure control agent followed by coupling then hydrogenation: a diblock polymer anion, S-B-Li, was prepared by charging 348 kg of cyclohexane and 26 kg, of styrene to a reactor.

5 The reactor temperature was increased to about 40°C. Impurities were removed by adding small aliquots of s-butyllithium until the first evidence of color. 3,160 milliliters of a solution of an approximately 12%wt solution of s-butyllithium in cyclohexane was added, and the styrene was allowed to complete polymerization at about 60°C. The molecular weight of the polystyrene produced in this reaction was determined to be 6,200 by GPC.  
10 The temperature was maintained at 60°C, 450 g. of 1,2 – diethoxypropane were added, and then 90 kg of butadiene were added at such a rate as to allow the temperature to remain about 60°C. A sample collected at the end of the butadiene polymerization had a styrene content of 22%wt and a vinyl  
15 content of 81% basis <sup>1</sup>H NMR and an overall molecular weight of 30,200 as determined by GPC. The butadiene was allowed to polymerize, and then 363 g of TESi was added, and the coupling reaction was allowed to proceed for 60 minutes at 60°C. Methanol (15 g, 0.1 mol per mol of Li) was added to terminate the reaction. The final product had a coupling efficiency of 89% and  
20 65% of the coupled species were linear with the remaining 35 % being 3-arm radial.

A sample of the polymer was hydrogenated to a residual olefin concentration of 0.17 meq/g in the presence of 20 ppm Ni/solution of a Nickel octanoate-aluminum triethyl catalyst (Al/Ni = 2.1 mol/mol). After hydrogenation under  
25 these conditions, the polymer was 89% coupled. The catalyst was removed by washing with aqueous phosphoric acid, and the polymer was recovered via steam stripping, under conditions typical for hydrogenated polymers.

Samples were taken so that the molecular weight of the styrene block and butadiene blocks could be determined. The amount of butadiene in the 1,2  
30 configuration before hydrogenation and the coupling efficiency was also

determined. The hydrogenated block copolymer was tested for melt flow and ODT. The results of the testing are displayed below in Table 1.

### Example 3

- 5 A hydrogenated block copolymer was prepared by anionic polymerization of styrene and then butadiene in the presence of a microstructure control agent followed by coupling then hydrogenation: a diblock polymer anion, S-B-Li, was prepared by charging 243 kg of cyclohexane and 20 kg, of styrene to a reactor. The reactor temperature was increased to about 40°C. Impurities were  
10 removed by adding small aliquots of s-butyllithium until the first evidence of color. 2,500 milliliters of a solution of an approximately 12%wt solution of s-butyllithium in cyclohexane was added, and the styrene was allowed to complete polymerization at about 60°C. The molecular weight of the polystyrene produced in this reaction was determined to be 6,100 by GPC.
- 15 The temperature was maintained at 60°C, 210 g. of 1,2 – diethoxypropane were added, and then 60 kg of butadiene were added at such a rate as to allow the temperature to remain about 60°C. A sample collected at the end of the butadiene polymerization had a styrene content of 22%wt and a vinyl content of 76% basis <sup>1</sup>H NMR and an overall molecular weight of 27,700 as  
20 determined by GPC. The butadiene was allowed to polymerize, and then 243 g of TESi was added, and the coupling reaction was allowed to proceed for 60 minutes at 60°C. The final product had a coupling efficiency of 94% and 62% of the coupled species were linear with the remaining 38% being 3-arm radial.
- 25 A sample of the polymer was hydrogenated to a residual olefin concentration of 0.17 meq/g in the presence of 10 ppm Ni/solution of a Nickel octanoate-aluminum triethyl catalyst (Al/Ni = 2.1 mol/mol). After hydrogenation under these conditions, the polymer remained 89% coupled. The catalyst was removed by washing with aqueous phosphoric acid, and the polymer was  
30 recovered via steam stripping, under conditions typical for hydrogenated polymers.

Samples were taken such that the molecular weight of the styrene block and butadiene blocks could be determined. The amount of butadiene in the 1,2 configuration before hydrogenation and the coupling efficiency was also determined. The hydrogenated block copolymer was tested for melt flow and ODT. The results of the testing are displayed below in Table 1.

#### Example 4

A polymer was prepared by the method of examples 2 and 3 where the styrene and butadiene charges were changed such that the styrene block had a molecular weight of 6,200, the overall molecular weight before coupling was 33,200, the vinyl content was 78% and the degree of coupling was 97%. After hydrogenation the coupling efficiency was 96% and the residual unsaturation was 0.1 meq/g.

#### Example 5

A polymer was prepared by the method of examples 2 and 3 with the exception that methyl trimethoxy silane was used as the coupling agent. The styrene and butadiene charges were such that the styrene block had a molecular weight of 6,200, the overall molecular weight before coupling was 32,800, the vinyl content was 76 and the degree of coupling was 94.

#### Example 6

A polymer was prepared by the method of examples 2 and 3 with the exception that tetramethoxy silane was used as the coupling agent. The styrene and butadiene charges were such that the styrene block had a molecular weight of 6,100, the overall molecular weight before coupling was 34,500, the vinyl content was 76 and the degree of coupling was 95.

#### Comparative Examples I, II and III

Comparative hydrogenated block copolymers I and II were prepared and tested substantially identically to Example 2 except that the styrene block molecular weight was greater than the maximum molecular weight of the invention. Comparative example III was prepared by sequential polymerization  
 5 of styrene then butadiene then styrene followed by hydrogenation. The results of the testing are displayed below in Table 1.

10

**Table 1**

Example #	S Block mwt (k)	E Block mwt (k)	Coupling Efficiency	1,2-butadiene in E block %	ODT °C	Melt Index
1	6.4	27.7	91	68	250	18
2	6.2	24.0	89	81	230	81
3	6.1	21.6	94	76	230	72
4	6.2	27.0	97	78	240	17
5	6.2	26.6	94	76	<250	31
6	6.1	28.5	95	76	<250	20
I	7.5	30.8	84	67	260	10
II	7.9	26.8	92	69	300+	6
III	7.2	55.8	8.5*	68	300+	7

The molecular weight values listed are true molecular weights determined using Gel Permeation Chromatography and Polystyrene standards.

The ODT's were measured using a Bohlin VOR rheometer.

15 Melt Index Test Method [230°C, 2.16KG, ASTM D-1238]

Examples 1-4 and Comparative Examples I to III showed that the molecular weight of the S block can have a significant effect on melting index and/or ODT.

20

#### Examples 5-7

Films were prepared from some of the polymers in Table 1 by adding 0.15% release agent and 0.02% Ethanox 330 stabilizer followed by extrusion on a Davis Standard cast film line at 230°C. Polymers 2 and 3 gave low extrusion

pressures and formed smooth, clear films because of their high flow. Comparative example III formed rougher films with high extrusion backpressure. The tensile and hysteresis properties of these films measured in the direction of extrusion according to ASTM D412 are shown in Table 2. All  
 5 show excellent strength and elasticity, as demonstrated by the high first cycle recovery and low permanent set after elongation to 300%.

10

**Table 2**

<b>EXAMPLE No.</b>	<b>5</b>	<b>6</b>	<b>7</b>
<b>POLYMER</b>	<b>2</b>	<b>3</b>	<b>III</b>
<b>PROPERTIES</b>	<b>MD</b>	<b>MD</b>	<b>MD</b>
<b>Stress-Strain at 2 in/min</b>			
Max. Stress at Break (psi)	1887	1584	2044
Strain at Break (%)	970	938	922
Stress at 100%, psi	206	177	205
Stress at 300%, psi	440	382	429
<b>Hysteresis to 300 %, 3 cycle.</b>			
Cycle 1 recovery	74	75	81
Permanent set (%)	9	8	10
Max stress (psi)	404	358	346

#### Examples 8-16

15 The polymer of Example 3 was compounded with a polypropylene copolymer with a melt flow of 30, Dow Chemical 6D43, a low molecular weight polypropylene homopolymer, Estaflex P1010 from Eastman Chemical, a hydrogenated hydrocarbon resin commercially available from Eastman Chemical as REGALREZ 1126 and a polystyrene commercially available from  
 20 Nova Chemical as NOVA 555 in the proportions shown in Table 3 using a Brabender mixer at 220°C, the mixer running at about 65RPM. The compounded hydrogenated copolymers were tested as above and the results are displayed below in Table 3.

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Table 3

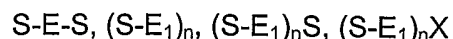
Example	8	9	10	11	12	13	14	15	16
	Fraction	Fraction	Fraction	Fraction	Fraction	Fraction	Fraction	Fraction	Fraction
Polymer 3	1	0.95	0.9	0.8	0.9	0.9	0.8	0.8	0.8
Dow 6D43 PP		0.05	0.1	0.2					0.07
Regalrez 1126						0.1	0.1	0.13	0.13
Eastoflex P1010					0.1			0.07	
Nova 555 PS							0.1		
Ethanox 330	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
Total (g)	43.2	43.2	43.2	43.2	43.2	42.43	42.43	43.2	43.2
<b>PROPERTIES</b>									
Clarity	Clear	Clear	Clear	Hazy	Clear	Clear	Hazy	Clear	Clear
<b>Stress-Strain at 2 in/min</b>									
Max. Stress at Break, psi	1678	1406	1401	1239	1152	1350	1304	1266	1336
Strain at Break, %	936	915	932	747	951	1028	832	1082	1032
Stress at 100%, psi	224	233	244	321	180	178	132	130	175
Stress at 300%, psi	450	451	465	666	359	348	327	272	356
<b>Hysteresis to 300 %, 3 cycle.</b>									
Cycle 1 recovery	73	65	60	52	68	70	84	75	65
Permanent set (%)	16	20	21	26	20	20	20	18	22
Max stress (psi)	338	348	329	497	302	281	220	212	289

- 5 Examples 9, 10 and 11 showed that polypropylene can be added to increase stiffness as shown by the modulus at 100 and 300% elongation, at the expense of hysteresis recovery. Example 12 showed that adding the less crystalline P1010 polypropylene decreases modulus as does the addition of tackifying resin Regalrez 1126. Combinations of tackifying resins and PS or PP
- 10 can be used to increase flow or stiffness while maintaining clarity, however, the base polymer without modification retained a superior balance of properties compared to most of the compounds. This demonstrated the importance of

making articles in a practical process using the neat polymer with a minimum amount of additives.

**WHAT IS CLAIMED IS:**

1. A selectively hydrogenated block copolymer having an S block and an E or E<sub>1</sub> block and having the general formula:



5 or mixtures thereof, wherein:

(a) prior to hydrogenation the S block is a polystyrene block;

(b) prior to hydrogenation the E block is a polydiene block, selected from polybutadiene, polyisoprene and mixtures thereof, having a molecular weight of from 40,000 to 70,000;

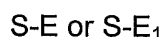
10 (c) prior to hydrogenation the E<sub>1</sub> block is a polydiene block, selected from polybutadiene, polyisoprene and mixtures thereof, having a molecular weight of from 20,000 to 35,000;

(d) n is an integer having a value of 2 to 6 and X is a coupling agent residue;

15 (e) the styrene content of the block copolymer is from 13 percent to 25 weight percent;

(f) the vinyl content of the polydiene block prior to hydrogenation is from 70 to 85 mol percent;

20 (g) the block copolymer includes less than 15 weight percent lower molecular weight units having the general formula:



wherein S, E and E<sub>1</sub> are as already defined;

25 (h) subsequent to hydrogenation about 0-10% of the styrene double bonds have been hydrogenated and at least 80% of the conjugated diene double bonds have been hydrogenated;

(i) the molecular weight of each of the S blocks is from 5,000 to 7,000; and

30 (j) the melt index of the block copolymer is greater than or equal to 12 grams/10 minutes according to ASTM D1238 at 230°C and 2.16 kg weight.

2. A block copolymer according to Claim 1, wherein the order-disorder temperature (ODT) of the block copolymer is less than 250°C.
3. A block copolymer according to Claim 1 or Claim 2, wherein the styrene content of the block copolymer is from 15 percent to 24 weight percent and the vinyl content of the polydiene block is from 73 to 83 mol percent.
4. A block copolymer according to any one of Claims 1 to 3 wherein the molecular weight each of the S blocks is from 5,800 to 6,600.
5. A block copolymer according to any one of Claims 1 to 4, wherein the E or E<sub>1</sub> block has a degree of hydrogenation greater than 90%.
6. A block copolymer according to any one of Claims 1 to 5, having an order-disorder temperature of from 210°C to 240°C.
7. A block copolymer according to any one of Claims 1 to 6, having a hysteresis recovery of greater than 50%, and a permanent set of less than 20% on the first retraction cycle after elongation to 300%.
8. An article selected from a: film, sheet, coating, band, strip, profile, tube, molding, foam, tape, fabric, thread, filament, ribbon, fiber, plurality of fibers and fibrous web; wherein the article is prepared by a process selected from injection molding, insert molding, over molding, dipping, extrusion, rotomolding, slush molding, fiber spinning, film making, and foaming and wherein the article is prepared using the hydrogenated block copolymer of any one of Claims 1 to 7.
9. An article according to Claim 8, wherein the hydrogenated block copolymer additionally comprises up to about 25 weight percent of one or more additives selected from the group consisting of olefin polymers, styrene

polymers, tackifying resins, polymer extending oils, fillers, reinforcements, lubricants, engineering thermoplastic resins, and mixtures thereof.

10. An article according to Claim 9, wherein the additive is selected from a polyethylene or polypropylene homopolymer or copolymer that is a plastomer, elastomer or interpolymers or a high clarity polypropylene copolymer.

11. A block copolymer having an S block and an E or E<sub>1</sub> block and having the general formula:

10 
$$S-E-S, (S-E)_n, (S-E)_nS, (S-E)_nX$$

or mixtures thereof, wherein:

- (a) the S block is a polystyrene block;
- (b) the E block is a polydiene block, selected from polybutadiene, polyisoprene and mixtures thereof, having a molecular weight of from 40,000 to 70,000;
- 15 (c) the E<sub>1</sub> block is a polydiene block, selected from polybutadiene, polyisoprene and mixtures thereof, having a molecular weight of from 20,000 to 35,000;
- (d) n is an integer having a value of 2 to 6 and X is a coupling agent residue;
- 20 (e) the styrene content of the block copolymer is from 13 percent to 25 percent;
- (f) the vinyl content of the polydiene block is from 70 to 85 percent;
- (g) the block copolymer includes less than 15 weight percent lower molecular weight units having the general formula:
- 25 
$$S-E \text{ or } S-E_1$$

wherein S, E and E<sub>1</sub> are as already defined; and

(h) the molecular weight of each of the S blocks is from 5,000 to 7,000.