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(54) Title: MULTIMODAL POLYMER

(57) **Abrégé/Abstract:**

A multimodal ethylene polymer with a density of less than 950 kg/m³ obtained by polymerisation with a single-site catalyst and having an MFR₂₁ in the range of 10 to 20 g/10min; a shear thinning index SHI_{2.7/210} of at least 4; and preferably a crosslinkability of at least 60%.



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(54) **Title:** MULTIMODAL POLYMER

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Multimodal Polymer

This invention concerns a process for the manufacture of a cross-linkable multimodal polyethylene as well as the cross-linkable multimodal polyethylene itself. The invention also covers a cross-linked polyethylene and articles, preferably pipes, made from the cross-linked polyethylene.

The use of polymers for pipes for various purposes, such as fluid transport, e.g. transport of liquids or gases such as water or natural gas is known. It is common for the fluid to be pressurised in these pipes. Such pipes can be made of polyethylene such as medium density polyethylene (MDPE) or high density polyethylene (HDPE), typically having a density of about 950 kg/m^3 .

Related disclosures EP-A-1927626 and EP-A-1927627 describe a pipe formed from a lower molecular weight copolymer component and a higher molecular weight homopolymer component having a density of less than 940 kg/m^3 .

Pipes can be manufactured using various techniques such as RAM extrusion or screw extrusion. Screw extrusion is one of the core operations in polymer processing and is also a key component in many other processing operations. An important aim in a screw extrusion process is to build pressure in a polymer melt so that it can be extruded through a die.

Crosslinking improves parameters such as heat deformation resistance and therefore pipes for hot water applications, such as pipes for floor heating, or for hot water distribution, are usually made of crosslinked polyethylene (PEX). However, prior art pipes such as pipes of crosslinked unimodal high density polyethylene (HDPE-X) have several drawbacks. In order to meet the high demands of the so-called HDPE-X norm for hot and cold water applications (e.g. EN ISO 15875) it is necessary to use polyethylene of a relatively high density. This makes the resulting pipe relatively stiff. This stiffness becomes even more pronounced when barrier layers are applied on top of or within the core pipe.

In order to improve the crosslinking response and hence reduce the consumption of crosslinking agent, e.g. peroxide, when crosslinking pipes of polyethylene, it is generally desired to use an ethylene polymer of relatively low

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melt flow rate (MFR), i.e. high molecular weight. However, this results in the drawback of poor processability, i.e. a reduced line speed at extrusion.

It is generally difficult therefore to achieve good processability and sufficient cross-linkability in the same polymer. The present inventors sought to solve the problems of good cross-linking ability combined with good processability, in particular in a screw extrusion process.

It is an object of the present invention to provide a polymer composition with improved crosslinking response, e.g. with a cross-linking degree of at least 60% and flexibility and with good processability making pipe manufacture, especially using screw extrusion, possible. The inventors' experience is that it is difficult to manufacture a polymer which is both excellent in terms of its processability and which still provides sufficient crosslinkability. To maintain good processability in a screw extrusion process, a balance between M_w and M_w/M_n is needed. In the case of single site produced polyethylene (SSC PE), bi or multimodal resins are therefore desired. Furthermore, to avoid yellowness, gels and inhomogenities, it is desirable to use resins with as low ash content as possible, i.e. the resin should be made with a catalyst with high activity.

The inventors have now found that a particular polymer possesses all these features.

Thus viewed from a first aspect the invention provides a multimodal ethylene polymer with a density of less than 950 kg/m^3 obtained by polymerisation with a single-site catalyst and having

an MFR_{21} in the range of 10 to 20 g/10min,
a shear thinning index $SHI_{2.7/210}$ of at least 4; and preferably
a crosslinkability of at least 60%.

Viewed from a second aspect the invention provides a polymer composition comprising a multimodal ethylene polymer as hereinbefore defined and at least one additive and/or other olefinic component.

Viewed another aspect the invention provides a process for the preparation of a multimodal ethylene polymer comprising:

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(I) polymerising ethylene and optionally at least one comonomer in a first stage in the presence of a single site catalyst;

(II) polymerising ethylene and optionally at least one comonomer in a second stage in the presence of the same single site catalyst;

5 so as to form an ethylene polymer as hereinbefore described, e.g. a multimodal ethylene polymer with a density of less than 950 kg/m^3 obtained by polymerisation with a single-site catalyst and having

an MFR_{21} in the range of 10 to 20 g/10min,

a shear thinning index $\text{SHI}_{2.7/210}$ of at least 4; and preferably

10 a crosslinkability of at least 60%.

Viewed from another aspect the invention provides a cross-linked polyethylene comprising a multimodal ethylene polymer as hereinbefore defined which has been cross-linked.

Viewed from another aspect the invention provides the use of a multimodal ethylene polymer as hereinbefore described in the manufacture of a pipe, especially a cross-linked pipe.

Viewed from another aspect the invention provides a process for the preparation of a crosslinked ethylene polymer pipe comprising forming the ethylene polymer as hereinbefore described into a pipe by extrusion, especially screw extrusion and crosslinking it.

Multimodal Ethylene Polymer

By ethylene polymer is meant a polymer in which ethylene is the major repeating unit, e.g. at 70 wt% ethylene, preferably at least 85 wt% ethylene.

The ethylene polymer of the present invention has a density of less than 950 kg/m^3 , preferably less than 949 kg/m^3 , preferably at most 947 kg/m^3 . Ideally the polymer will have a density of at least 920 kg/m^3 , e.g. at least 925 kg/m^3 . A preferred density range may be 932 to less than 950 kg/m^3 , especially 940 to less than 950 kg/m^3 . This density is made possible by the single-site catalysed polymerisation of the ethylene polymer and has several advantages. The lower than normal density polymer means that the pipe prepared therefrom is more flexible.

This is of importance, *inter alia*, for pipes intended, e.g. for floor heating. Further, a lower density ethylene polymer base resin means a lower crystallinity which in turn means that less energy is required to melt the polymer. This results in an enhanced production speed when manufacturing pipes.

5 Still further and importantly, the lower density/crystallinity single-site catalysed ethylene polymer of the present invention surprisingly gives the same or improved pressure test performance as prior art materials with higher density/crystallinity, i.e. a certain pressure test performance can be obtained with a more flexible pipe according to the present invention than with a traditional material
10 with higher density and crystallinity.

The ethylene polymer of the invention preferably has a MFR₂₁ of 10-20 g/10 min, more preferably 11 to 19 g/10 min, especially 12 to 18 g/10min, e.g. 13 to 17 g/10min.

The MFR is an indication of the flowability, and hence the processability, of
15 the polymer. The higher the melt flow rate, the lower the viscosity of the polymer. MFR is also important to ensure sufficient cross-linking ability. The very narrow range for MFR₂₁ ensures that the cross-linking ability of the claimed polymer is excellent. If the MFR₂₁ is less than 10 g/10min extrudability performance is poor leading to articles with poor surface quality. If the MFR₂₁ is greater than 20
20 g/10min, the necessary cross-linking degree is not achieved.

MFR₅ values may range from 0.1 to 5 g/10 min. Ideally the MFR₅ value is in the range 0.5 to 3 g/10min.

The ethylene polymers of the invention preferably have molecular weight, M_w of at least 100,000, preferably at least 120,000, especially at least 150,000.

25 M_n values are preferably at least 25,000, more preferably at least 30,000.

The preferably single-site catalysed ethylene polymer of the present invention has a broad molecular weight distribution as defined by its shear thinning index (SHI). The SHI is the ratio of the complex viscosity(η^*) at two different shear stresses and is a measure of the broadness (or narrowness) of the molecular weight
30 distribution.

According to the present invention the ethylene polymer has a shear thinning index SHI_{5/300}, i.e. a ratio of the complex viscosity at 190°C and a shear stress of 5

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kPa ($\eta^*_{5\text{kPa}}$) and the complex viscosity at 190°C and a shear stress of 300 kPa ($\eta^*_{300\text{kPa}}$), of at least 5, preferably at least 6.

According to the present invention the ethylene polymer has a shear thinning index $\text{SHI}_{2.7/210}$, i.e. a ratio of the complex viscosity at 190°C and a shear stress of 2.7 kPa ($\eta^*_{2.7\text{kPa}}$) and the complex viscosity at 190°C and a shear stress of 210 kPa ($\eta^*_{210\text{kPa}}$), of at least 4. Preferably $\text{SHI}_{2.7/210}$ is less than 10.

Another way to measure molecular weight distribution (MWD) is by GPC. The molecular weight distribution (MWD value i.e. M_w/M_n) according to the present invention more than 4. Preferably the MWD is less than 10, e.g. less than 8. This molecular weight distribution enhances crosslinkability, e.g. less peroxide or radiation is required to obtain a certain crosslinking degree.

According to a preferred embodiment of the invention the ethylene polymer has a complex viscosity at a shear stress of 5kPa/190°C, $\eta^*_{5\text{kPa}}$ of at least 10,000 Pas, more preferably at least 15,000 Pas.

According to another preferred embodiment of the invention the ethylene polymer has a complex viscosity at a shear stress of 0.05rad/s at 190°C, $\eta^*_{0.05\text{rad/s}}$, of at least 10,000 Pas, more preferably at least 15,000 Pas.

A further benefit of the process of the invention and hence of the polymers of the invention is low ash content and excellent particle size distribution. High ash content samples are more prone to oxidation and by using a two reactor process, the formed polymers have less ash and a much more even distribution of ash with absence of particles with very high ash content.

The ash content of the ethylene polymer of the invention may be less than 500 ppm, preferably less than 400 ppm, especially less than 350 ppm. It will be appreciated that ash contents are effected by polymerisation conditions, especially the partial pressure of ethylene used during the polymerisation. Lower ethylene partial pressures tend to cause more ash.

It is also observed that the process of the invention ensures a better ash content distribution (i.e. any ash present is distributed across a broader range of particles and is not concentrated in a particular polymer fraction). It has been noted that high levels of ash are particularly prevalent in smaller particles when the polymer is unimodal and made in a single polymerisation stage.

A low ash content is also associated with low yellowness indices for articles made from the polymer. Thus, articles made from the ethylene polymer of the invention (preferably the cross-linked ethylene polymer of the invention) may have yellowness indices of less than 2, preferably less than 1.5.

5 The multimodal ethylene polymer of the invention is produced in at least two stages, ideally two stages only, and therefore contains at least two fractions, preferably two fractions only.

The term "multimodal" means herein, unless otherwise stated, multimodality with respect to molecular weight distribution and includes therefore a bimodal
10 polymer. Usually, a polyethylene composition, comprising at least two polyethylene fractions, which have been produced under different polymerization conditions resulting in different (weight average) molecular weights and molecular weight distributions for the fractions, is referred to as "multimodal". The prefix "multi" relates to the number of different polymer fractions present in the polymer. Thus, for
15 example, multimodal polymer includes so called "bimodal" polymer consisting of two fractions. The form of the molecular weight distribution curve, i.e. the appearance of the graph of the polymer weight fraction as a function of its molecular weight, of a multimodal polymer will show two or more maxima or is typically distinctly broadened in comparison with the curves for the individual fractions. For
20 example, if a polymer is produced in a sequential multistage process, utilizing reactors coupled in series and using different conditions in each reactor, the polymer fractions produced in the different reactors will each have their own molecular weight distribution and weight average molecular weight. When the molecular weight distribution curve of such a polymer is recorded, the individual curves from
25 these fractions form typically together a broadened molecular weight distribution curve for the total resulting polymer product.

The multimodal polymer usable in the present invention comprises a lower weight average molecular weight (LMW) component and a higher weight average molecular weight (HMW) component. Said LMW component has a lower
30 molecular weight than the HMW component. This difference is preferably at least 5000 units.

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In one preferable embodiment, said multimodal polymer comprises at least (i) a lower weight average molecular weight (LMW) ethylene homopolymer or copolymer component, and (ii) a higher weight average molecular weight (HMW) ethylene homopolymer or copolymer component. Preferably, at least one of said LMW and HMW components is a copolymer of ethylene with at least one comonomer. It is preferred that at least said HMW component is an ethylene copolymer. Alternatively, if one of said components is a homopolymer, then said LMW is preferably the homopolymer.

Alternatively, said multimodal ethylene polymer may comprise further polymer components, e.g. three components being a trimodal ethylene polymer. Optionally multimodal ethylene polymers of the invention may also comprise e.g. up to 10 % by weight of a well known polyethylene prepolymer which is obtainable from a prepolymerisation step as well known in the art, e.g. as described in WO9618662. In case of such prepolymer, the prepolymer component is comprised in one of LMW and HMW components, preferably LMW component, as defined above.

Preferably said multimodal polymer is bimodal comprising said LMW and HMW components and optionally a prepolymerised fraction as defined above.

Said LMW component of multimodal polymer preferably has a MFR₂ of at least 5 g/10 min, preferably below 50 g/10 min, e.g. up to 40 g/10 min, such as between 5 to 20 g/10 min.

The density of LMW component of said multimodal polymer may range from 930 to 980 kg/m³, e.g. 930 to 970 kg/m³, more preferably 935 to 960 kg/m³.

The LMW component of said multimodal polymer may form from 30 to 70 wt%, e.g. 40 to 60% by weight of the multimodal polymer with the HMW component forming 70 to 30 wt%, e.g. 40 to 60% by weight. In one embodiment said LMW component forms 50 wt% or more of the multimodal polymer as defined above or below.

The HMW component of said multimodal ethylene polymer has a lower MFR₂ than the LMW component.

The ethylene polymer of the invention may be an ethylene homopolymer or copolymer. By ethylene homopolymer is meant a polymer which is formed

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essentially only ethylene monomer units, i.e. is 99.9 wt% ethylene or more. It will be appreciated that minor traces of other monomers may be present due to industrial ethylene containing trace amounts of other monomers.

The ethylene polymer of the invention may also be a copolymer and can therefore be formed from ethylene with at least one other comonomer, e.g. C₃₋₂₀ olefin. Preferred comonomers are alpha-olefins, especially with 3-8 carbon atoms. Other comonomers of value are dienes. The use of dienes as comonomer increases the level of unsaturation in the polymer and thus is a way to further enhance crosslinkability. Preferred dienes are C₄₋₂₀-dienes where at least one double bond is at the 1-position of the diene. Especially preferred dienes are dienes containing a tertiary double bond. By the term "tertiary double bond" is meant herein a double bond that is substituted by three non-hydrogen groups (e.g. by three alkyl groups).

Preferably, the comonomer is selected from the group consisting of propene, 1-butene, 1-hexene, 4-methyl-1-pentene, 1-octene, 1,7-octadiene and 7-methyl- 1,6-octadiene.

The polymers of the invention can comprise one monomer or two monomers or more than 2 monomers. The use of a single comonomer is preferred. If two comonomers are used it is preferred if one is an C₃₋₈ alpha-olefin and the other is a diene as hereinbefore defined.

The amount of comonomer is preferably such that it comprises 0-3 mol%, more preferably 0-1.5 mol% and most preferably 0-1 mol% of the ethylene polymer.

It is preferred however if the ethylene polymer of the invention comprises a LMW homopolymer component and a HMW ethylene copolymer component, e.g. an ethylene hexene copolymer.

The polymer of the invention is prepared by single-site catalysed polymerisation and has a relatively low density and a narrow molecular weight distribution. The use of a single-site catalysed ethylene polymer gives better pressure test performance for a given density level than corresponding prior art materials. Therefore, a polymer of lower density may be used which results in a more flexible pipe. Moreover, a polymer of lower density also requires less energy to melt which is beneficial in terms of pipe manufacturing. Further, the use of single site catalysed low MFR polymer allows a lower amount of crosslinking agent to be

used to reach the desired degree of crosslinking. The polyethylene as defined above useful may be made using any conventional single site catalysts, including metallocenes and non-metallocenes as well known in the field.

5 Preferably said catalyst is one comprising a metal coordinated by one or more η -bonding ligands. Such η -bonded metals are typically transition metals of Group 3 to 10, e.g. Zr, Hf or Ti, especially Zr or Hf. The η -bonding ligand is typically an η^5 -cyclic ligand, i.e. a homo or heterocyclic cyclopentadienyl group optionally with fused or pendant substituents. Such single site, preferably metallocene, procatalysts have been widely described in the scientific and patent literature for about twenty years. Procatalyst refers herein to said transition metal complex.

The metallocene procatalyst may have a formula II:



15

wherein:

each Cp independently is an unsubstituted or substituted and/or fused homo- or heterocyclopentadienyl ligand, e.g. substituted or unsubstituted cyclopentadienyl, substituted or unsubstituted indenyl or substituted or unsubstituted fluorenyl ligand;

20

the optional one or more substituent(s) being independently selected preferably from halogen, hydrocarbyl (e.g. C₁-C₂₀-alkyl, C₂-C₂₀-alkenyl, C₂-C₂₀-alkynyl, C₃-C₁₂-cycloalkyl, C₆-C₂₀-aryl or C₇-C₂₀-arylalkyl), C₃-C₁₂-cycloalkyl which contains 1, 2, 3 or 4 heteroatom(s) in the ring moiety, C₆-C₂₀-heteroaryl, C₁-C₂₀-haloalkyl, -SiR"₃, -OSiR"₃, -SR", -PR"₂ or -NR"₂,

25

each R" is independently a hydrogen or hydrocarbyl, e.g. C₁-C₂₀-alkyl, C₂-C₂₀-alkenyl, C₂-C₂₀-alkynyl, C₃-C₁₂-cycloalkyl or C₆-C₂₀-aryl; or e.g. in case of -NR"₂, the two substituents R" can form a ring, e.g. five- or six-membered ring, together with the nitrogen atom to which they are attached;

30

R is a bridge of 1-7 atoms, e.g. a bridge of 1-4 C-atoms and 0-4 heteroatoms, wherein the heteroatom(s) can be e.g. Si, Ge and/or O atom(s), wherein each of the bridge atoms may bear independently substituents, such as C₁₋₂₀-alkyl, tri(C₁₋₂₀-alkyl)silyl, tri(C₁₋₂₀-alkyl)siloxy or C₆₋₂₀-aryl substituents); or a bridge of 1-3, e.g.

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one or two, hetero atoms, such as silicon, germanium and/or oxygen atom(s), e.g. -SiR¹₂-, wherein each R¹ is independently C₁₋₂₀-alkyl, C₆₋₂₀-aryl or tri(C₁₋₂₀-alkyl)silyl-residue, such as trimethylsilyl;

M is a transition metal of Group 3 to 10, preferably of Group 4 to 6, such as Group 4, e.g. Ti, Zr or Hf, especially Hf;

each X is independently a sigma-ligand, such as H, halogen, C₁₋₂₀-alkyl, C₁₋₂₀-alkoxy, C₂-C₂₀-alkenyl, C₂-C₂₀-alkynyl, C₃-C₁₂-cycloalkyl, C₆-C₂₀-aryl, C₆-C₂₀-aryloxy, C₇-C₂₀-arylalkyl, C₇-C₂₀-arylalkenyl, -SRⁿ, -PRⁿ₃, -SiRⁿ₃, -OSiRⁿ₃, -NRⁿ₂ or -CH₂-Y, wherein Y is C₆-C₂₀-aryl, C₆-C₂₀-heteroaryl, C₁-C₂₀-alkoxy, C₆-C₂₀-aryloxy, NRⁿ₂, -SRⁿ, -PRⁿ₃, -SiRⁿ₃, or -OSiRⁿ₃;

each of the above mentioned ring moieties alone or as a part of another moiety as the substituent for Cp, X, Rⁿ or R¹ can further be substituted e.g. with C₁-C₂₀-alkyl which may contain Si and/or O atoms;

n is 0, 1 or 2, e.g. 0 or 1,

m is 1, 2 or 3, e.g. 1 or 2,

q is 1, 2 or 3, e.g. 2 or 3,

wherein m+q is equal to the valency of M.

Suitably, in each X as -CH₂-Y, each Y is independently selected from C₆-C₂₀-aryl, NRⁿ₂, -SiRⁿ₃ or -OSiRⁿ₃. Most preferably, X as -CH₂-Y is benzyl. Each X other than -CH₂-Y is independently halogen, C₁-C₂₀-alkyl, C₁-C₂₀-alkoxy, C₆-C₂₀-aryl, C₇-C₂₀-arylalkenyl or -NRⁿ₂ as defined above, e.g. -N(C₁-C₂₀-alkyl)₂.

Preferably, q is 2, each X is halogen or -CH₂-Y, and each Y is independently as defined above.

Cp is preferably cyclopentadienyl, indenyl, tetrahydroindenyl or fluorenyl, optionally substituted as defined above.

In a suitable subgroup of the compounds of formula II, each Cp independently bears 1, 2, 3 or 4 substituents as defined above, preferably 1, 2 or 3, such as 1 or 2 substituents, which are preferably selected from C₁-C₂₀-alkyl, C₆-C₂₀-aryl, C₇-C₂₀-arylalkyl (wherein the aryl ring alone or as a part of a further moiety may further be substituted as indicated above), -OSiRⁿ₃, wherein Rⁿ is as indicated above, preferably C₁-C₂₀-alkyl.

R, if present, is preferably a methylene, ethylene or a silyl bridge, whereby the silyl can be substituted as defined above, e.g. a (dimethyl)Si=,
 5 (methylphenyl)Si= or (trimethylsilylmethyl)Si=; n is 0 or 1; m is 2 and q is two. Preferably, R" is other than hydrogen.

A specific subgroup includes the well known metallocenes of Zr, Hf and Ti with two η -5-ligands which may be bridged or unbridged cyclopentadienyl ligands optionally substituted with e.g. siloxy, or alkyl (e.g. C₁₋₆-alkyl) as defined above, or
 10 with two unbridged or bridged indenyl ligands optionally substituted in any of the ring moieties with e.g. siloxy or alkyl as defined above, e.g. at 2-, 3-, 4- and/or 7-positions. Preferred bridges are ethylene or -SiMe₂.

The preparation of the metallocenes can be carried out according or analogously to the methods known from the literature and is within skills of a person
 15 skilled in the field. Thus for the preparation see e.g. EP-A-129 368, examples of compounds wherein the metal atom bears a -NR"₂ ligand see i.a. in WO-A-9856831 and WO-A-0034341. For the preparation see also e.g. in EP-A-260 130, WO-A-9728170, WO-A-9846616, WO-A-9849208, WO-A-9912981, WO-A-9919335, WO-A-9856831, WO-A-00/34341, EP-A-423 101 and EP-A-537 130.

20 Alternatively, in a further subgroup of the metallocene compounds, the metal bears a Cp group as defined above and additionally a η 1 or η 2 ligand, wherein said ligands may or may not be bridged to each other. Such compounds are described e.g. in WO-A-9613529.

Further preferred metallocenes include those of formula (I)
 25 Cp'₂HfX'₂

wherein each X' is halogen, C₁₋₆ alkyl, benzyl or hydrogen;

Cp' is a cyclopentadienyl or indenyl group optionally substituted by a C₁₋₁₀ hydrocarbyl group or groups and being optionally bridged, e.g. via an ethylene or
 30 dimethylsilyl link.

Especially preferred catalysts are bis- (n-butyl cyclopentadienyl) hafnium dichloride, bis- (n-butyl cyclopentadienyl) zirconium dichloride and

bis- (n-butyl cyclopentadienyl) hafnium dibenzyl, the last one being especially preferred.

5 Metalocene procatalysts are generally used as part of a catalyst system which also includes a catalyst activator, called also as cocatalyst. Useful activators are, among others, aluminium compounds, like aluminium alkoxy compounds. Suitable aluminium alkoxy activators are for example methylaluminoxane (MAO), hexaisobutylaluminoxane and tetraisobutylaluminoxane. In addition boron compounds (e.g. a fluoroboron compound such as triphenylpentafluoroboron or triphenylcarbenium tetrakis(pentafluoroborate) $((C_6H_5)_3B^+B^-(C_6F_5)_4)$) can be used as activators. The cocatalysts and activators and the preparation of such catalyst systems is well known in the field. For instance, when an aluminium alkoxy compound is used as an activator, the Al/M molar ratio of the catalyst system (Al is the aluminium from the activator and M is the transition metal from the transition metal complex) is suitable from 50 to 500 mol/mol, preferably from 100 to 400 mol/mol. Ratios below or above said ranges are also possible, but the above ranges are often the most useful.

10 If desired the procatalyst, procatalyst/cocatalyst mixture or a procatalyst/cocatalyst reaction product may be used in supported form (e.g. on a silica or alumina carrier), unsupported form or it may be precipitated and used as such. One feasible way for producing the catalyst system is based on the emulsion technology, wherein no external support is used, but the solid catalyst is formed from by solidification of catalyst droplets dispersed in a continuous phase. The solidification method and further feasible metallocenes are described e.g. in WO03/051934.

25 It is also possible to use combinations of different activators and procatalysts. In addition additives and modifiers and the like can be used, as is known in the art.

30 Any catalytically active catalyst system including the procatalyst, e.g. metallocene complex, is referred herein as single site or metallocene catalyst (system).

Preparation of cross-linkable polymer

For the preparation of the ethylene polymer of the present invention polymerisation methods well known to the skilled person may be used. It is within the scope of the invention for a multimodal, e.g. at least bimodal, polymer to be produced by blending each of the components in-situ during the polymerisation process thereof (so called in-situ process) or, alternatively, by blending mechanically two or more separately produced components in a manner known in the art. The multimodal polyethylene useful in the present invention is preferably obtained by in-situ blending in a multistage polymerisation process. Accordingly, polymers are obtained by in-situ blending in a multistage, i.e. two or more stage, polymerization process including solution, slurry and gas phase process, in any order. Whilst it is possible to use different single site catalysts in each stage of the process, it is preferred if the catalyst employed is the same in both stages.

Ideally therefore, the polyethylene polymer of the invention is produced in at least two-stage polymerization using the same single site catalyst. Thus, for example two slurry reactors or two gas phase reactors, or any combinations thereof, in any order can be employed. Preferably however, the polyethylene is made using a slurry polymerization in a loop reactor followed by a gas phase polymerization in a gas phase reactor.

A loop reactor - gas phase reactor system is well known as Borealis technology, i.e. as a BORSTARTM reactor system. Such a multistage process is disclosed e.g. in EP517868.

The conditions used in such a process are well known. For slurry reactors, the reaction temperature will generally be in the range 60 to 110°C, e.g. 85-110°C, the reactor pressure will generally be in the range 5 to 80 bar, e.g. 50-65 bar, and the residence time will generally be in the range 0.3 to 5 hours, e.g. 0.5 to 2 hours. The diluent used will generally be an aliphatic hydrocarbon having a boiling point in the range -70 to +100°C, e.g. propane. In such reactors, polymerization may if desired be effected under supercritical conditions. Slurry polymerisation may also be carried out in bulk where the reaction medium is formed from the monomer being polymerised.

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For gas phase reactors, the reaction temperature used will generally be in the range 60 to 115°C, e.g. 70 to 110°C, the reactor pressure will generally be in the range 10 to 25 bar, and the residence time will generally be 1 to 8 hours. The gas used will commonly be a non-reactive gas such as nitrogen or low boiling point hydrocarbons such as propane together with monomer, e.g. ethylene.

A chain-transfer agent, preferably hydrogen, can be added as required to the reactors. It is preferred if the amount of hydrogen used in the manufacture of the first component is very low. Preferably therefore, the amount is less than 1, preferably less than 0.5, e.g. 0.01 to 0.5 mol of H₂/kmoles of ethylene are added to the first, e.g. loop reactor.

The amount of hydrogen added to the second reactor, typically gas phase reactor is also quite low. Values may range from 0.05 to 1, e.g. 0.075 to 0.5, especially 0.1 to 0.4 moles of H₂/kmoles of ethylene.

The ethylene concentration in the first, preferably loop, reactor may be around 5 to 15 mol%, e.g. 7.5 to 12 mol%.

In the second, preferably gas phase, reactor, ethylene concentration is preferably much higher, e.g. at least 40 mol% such as 45 to 65 mol%, preferably 50 to 60 mol%.

Preferably, the first polymer fraction is produced in a continuously operating loop reactor where ethylene is polymerised in the presence of a polymerization catalyst as stated above and a chain transfer agent such as hydrogen. The diluent is typically an inert aliphatic hydrocarbon, preferably isobutane or propane. The reaction product is then transferred, preferably to continuously operating gas phase reactor. The second component can then be formed in a gas phase reactor using preferably the same catalyst.

A prepolymerisation step may precede the actual polymerisation process.

The use of partial pressures in this range is advantageous and forms a further aspect of the invention which therefore provides a process for the preparation of a multimodal ethylene polymer comprising:

30

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(I) polymerising ethylene and optionally at least one comonomer in a first stage in the presence of a single site catalyst and at an ethylene partial pressure of between 5 and 15 mol%;

5 (II) polymerising ethylene and optionally at least one comonomer in a second stage in the presence of the same single site catalyst and at an ethylene partial pressure of at least 45 mol%;

so as to form an ethylene polymer as hereinbefore described.

The ethylene polymer of the invention can be blended with any other
10 polymer of interest or used on its own as the only olefinic material in an article. Thus, the ethylene polymer of the invention can be blended with known HDPE, MDPE, LDPE, LLDPE polymers or a mixture of ethylene polymers of the invention could be used. Ideally however any article made from the ethylene polymer is the invention consists essentially of the polymer, i.e. contains the ethylene polymer
15 along with standard polymer additives only.

The ethylene polymer of the invention may be blended with standard additives, fillers and adjuvants known in the art. It may also contain additional polymers, such as carrier polymers of the additive masterbatches. Preferably the ethylene polymer comprises at least 50 % by weight of any polymer composition
20 containing the ethylene polymer, preferably from 80 to 100 % by weight and more preferably from 85 to 100 % by weight, based on the total weight of the composition.

Suitable antioxidants and stabilizers are, for instance, sterically hindered phenols, phosphates or phosphonites, sulphur containing antioxidants, alkyl radical
25 scavengers, aromatic amines, hindered amine stabilizers and the blends containing compounds from two or more of the above-mentioned groups.

Examples of sterically hindered phenols are, among others, 2,6-di-tert-butyl -
4-methyl phenol (sold, e.g., by Degussa under a trade name of Ionol CPTM),
pentaerythrityl-tetrakis(3-(3',5'-di-tert. butyl-4-hydroxyphenyl)-propionate (sold,
30 e.g., by Ciba Specialty Chemicals under the trade name of Irganox 1010TM)
octadecyl-3-3(3'5'-di-tert-butyl-4'-hydroxyphenyl)propionate (sold, e.g., by Ciba Specialty Chemicals under the trade name of Irganox 1076TM) and 2,5,7,8-

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tetramethyl-2(4',8',12'-trimethyltridecyl)chroman-6-ol (sold, e.g., by BASF under the trade name of Alpha-TocopherolTM).

Examples of phosphates and phosphonites are tris (2,4-di-*t*-butylphenyl) phosphite (sold, e.g., by Ciba Specialty Chemicals under the trade name of Irgafos 168TM), tetrakis-(2,4-di-*t*-butylphenyl)-4,4'-biphenylen-di-phosphonite (sold, e.g.,
5 by Ciba Specialty Chemicals under the trade name of Irgafos P-EPQ) and tris-(nonylphenyl)phosphate (sold, e.g., by Dover Chemical under the trade name of Doverphos HiPure 4TM)

Examples of sulphur-containing antioxidants are dilaurylthiodipropionate
10 (sold, e.g., by Ciba Specialty Chemicals under the trade name of Irganox PS 800TM), and distearylthiodipropionate (sold, e.g., by Chemtura under the trade name of Lowinox DSTDBTM).

Examples of nitrogen-containing antioxidants are 4,4'-bis(1,1'-dimethylbenzyl)diphenylamine (sold, e.g., by Chemtura under the trade name of Naugard 445TM), polymer of 2,2,4-trimethyl-1,2-dihydroquinoline (sold, e.g., by
15 Chemtura under the trade name of Naugard EL-17TM), *p*-(*p*-toluene-sulfonylamido)-diphenylamine (sold, e.g., by Chemtura under the trade name of Naugard SATM) and *N,N'*-diphenyl-*p*-phenylene-diamine (sold, e.g., by Chemtura under the trade name of Naugard JTM).

20 Commercially available blends of antioxidants and process stabilizers are also available, such as Irganox B225TM, Irganox B215TM and Irganox B561TM marketed by Ciba-Specialty Chemicals.

Suitable acid scavengers are, for instance, metal stearates, such as calcium stearate and zinc stearate. They are used in amounts generally known in the art,
25 typically from 500 ppm to 10000 ppm and preferably from 500 to 5000 ppm.

Carbon black is a generally used pigment, which also acts as an UV-screener. Typically carbon black is used in an amount of from 0.5 to 5 % by weight, preferably from 1.5 to 3.0 % by weight. Preferably the carbon black is added as a masterbatch where it is premixed with a polymer, preferably high density
30 polyethylene (HDPE), in a specific amount. Suitable masterbatches are, among others, HD4394TM, sold by Cabot Corporation, and PPM1805TM by Poly Plast Muller. Also titanium oxide may be used as an UV-screener.

Applications

The polymer of the invention is cross-linkable and is ideal for use in the
5 formation of cross-linked pipes. Cross-linking of the polymer/pipe can be achieved
in conventional ways e.g. using peroxide, irradiation or silane cross-linkers. In
peroxide crosslinking, the crosslinking takes place by the addition of peroxide com-
pounds, such as dicumyl peroxide, which form free radicals. Cross-linking can also
be achieved by irradiation or using silanes. It is preferred however if the pipes of
10 this invention are prepared by irradiation cross-linking. The pipes of the invention
are preferably PEXc pipes.

At a predetermined amount of irradiation, a lower molecular weight (higher
MFR) polymer may be used than in the prior art. According to the present invention
the absence of very low molecular weight tail in single-site catalyst polymers results
15 in improved crosslinkability.

Low molecular weight polymers require a higher amount of peroxide to
achieve an efficient network structure.

Irradiation cross-linking is preferred, and can be carried out by firing an
electron beam onto the formed pipe. The dose used can vary but suitable doses
20 include 100 to 200 kGy, e.g. 150 to 200 kGy. Particular doses of interest are 160
kGy and 190 kGy.

The polymers of the invention can exhibit a cross-linking degree (i.e.
crosslinkability) of at least 60%, e.g. at least 65%. In particular, the ethylene
polymer of the invention may have a degree of crosslinking $\geq 60\%$ as measured by
25 the method described below.

The ethylene polymer of the invention may therefore exhibits a cross-linking
degree of at least 60% when tested according to the protocols below, i.e. when
formed into a pipe following the protocol below under the title "irradiation of pipe",
the cross-linking degree being measured by decaline extraction (measured according
30 to ASTM D2765-01 Method A). It is stressed however that the ethylene polymer of
the invention need not be cross-linked.

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In a preferred embodiment, the invention provides a cross-linked multimodal ethylene polymer with a density of less than 950 kg/m^3 obtained by polymerisation with a single-site catalyst and having

- an MFR_{21} in the range of 10 to 20 g/10min;
- 5 a shear thinning index $\text{SHI}_{2.7/210}$ of at least 4; and preferably
- a crosslinkability of at least 60%;
- and a pipe made therefrom.

The pipes of the invention also exhibit a cross-linking degree of at least 60%.

Pipes according to the present invention are produced according to the
10 methods known in the art. Thus, according to one preferred method the polymer composition is extruded through an annular die to a desired internal diameter, after which the polymer composition is cooled.

Extruders having a high length to diameter ratio L/D more than 15,
preferably of at least 20 and in particular of at least 25 are preferred. The modern
15 extruders typically have an L/D ratio of from about 30 to 35.

The polymer melt is extruded through an annular die, which may be arranged either as end-fed or side-fed configuration. The side-fed dies are often mounted with their axis parallel to that of the extruder, requiring a right-angle turn in the connection to the extruder. The advantage of side-fed dies is that the mandrel can be
20 extended through the die and this allows, for instance, easy access for cooling water piping to the mandrel.

After the plastic melt leaves the die it is calibrated to the correct diameter. In one method the extrudate is directed into a metal tube (calibration sleeve). The inside of the extrudate is pressurised so that the plastic is pressed against the wall of
25 the tube. The tube is cooled by using a jacket or by passing cold water over it.

According to another method a water-cooled extension is attached to the end of the die mandrel. The extension is thermally insulated from the die mandrel and is cooled by water circulated through the die mandrel. The extrudate is drawn over the mandrel which determines the shape of the pipe and holds it in shape during cooling.
30 Cold water is flowed over the outside pipe surface for cooling.

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According to still another method the extrudate leaving the die is directed into a tube having perforated section in the centre. A slight vacuum is drawn through the perforation to hold the pipe against the walls of the sizing chamber.

5 After the sizing the pipe is cooled, typically in a water bath having a length of about 5 metres or more.

The pipes according to the present invention preferably fulfil the requirements of PE80 standard as defined in EN 12201 and EN 1555, alternatively ISO 4427 and ISO 4437, evaluated according to ISO 9080. Especially preferably the pipes fulfil EN ISO 15875.

10 Generally, polymer pipes are manufactured by extrusion. A conventional plant for screw extrusion of PEX polymer pipes comprises a single or double screw extruder, a nozzle, a calibrating device, cooling equipment, a pulling device, and a device for cutting or for coiling-up the pipe. The polymer is extruded into a pipe from the extruder and thereafter the pipe is crosslinked. This screw extrusion
15 technique is well known to the skilled person and no further particulars should therefore be necessary here. The ethylene polymers of the invention are particularly suitable for screw extrusion.

The high cross-linking degree and other properties of the ethylene polymer of the invention allow the formation of articles, in particular pipes, which have
20 excellent surface quality, i.e. are free from blemishes and are smooth to the touch.

The pipes of the invention are particularly suited to carrying water, especially hot water.

It will be appreciated that the preferred features of the polymers of the invention as described herein can all be combined with each other in any way.

25 The invention will now be described with reference to the following non limiting examples.

Analytical tests

30 Melt Flow Rate

The melt flow rate (MFR) is determined according to ISO 1133 and is indicated in g/10 min. The MFR is an indication of the melt viscosity of the polymer. The MFR

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is determined at 190°C for polyethylene. The load under which the melt flow rate is determined is usually indicated as a subscript, for instance MFR₂ is measured under 2.16 kg load (condition D), MFR₅ is measured under 5 kg load (condition T) or MFR₂₁ is measured under 21.6 kg load (condition G).

5

The quantity FRR (flow rate ratio) is an indication of molecular weight distribution and denotes the ratio of flow rates at different loads. Thus, FRR_{21/2} denotes the value of MFR₂₁/MFR₂.

10 Density

Density of the polymer was measured according to ISO 1183 / 1872-2B.

For the purpose of this invention the density of the blend can be calculated from the densities of the components according to:

$$15 \quad \rho_b = \sum_i w_i \cdot \rho_i$$

where ρ_b is the density of the blend,

w_i is the weight fraction of component "i" in the blend and

ρ_i is the density of the component "i".

20 Molecular weight

M_w, M_n and MWD are measured by Gel Permeation Chromatography (GPC) according to the following method:

The weight average molecular weight M_w and the molecular weight distribution (MWD = M_w/M_n wherein M_n is the number average molecular weight and M_w is the weight average molecular weight) is measured according to ISO 16014-4:2003 and ASTM D 6474-99. A Waters GPCV2000 instrument, equipped with refractive index detector and online viscosimeter was used with 2 x GMHXL-HT and 1x G7000HXL-HT TSK-gel columns from Tosoh Bioscience and 1,2,4-trichlorobenzene (TCB, stabilized with 250 mg/L 2,6-Di tert-butyl-4-methyl-phenol) as solvent at 140 °C and at a constant flow rate of 1 mL/min. 209.5 μL of sample

30

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solution were injected per analysis. The column set was calibrated using universal calibration (according to ISO 16014-2:2003) with at least 15 narrow MWD polystyrene (PS) standards in the range of 1 kg/mol to 12 000 kg/mol. Mark Houwink constants were used as given in ASTM D 6474-99. All samples were prepared by dissolving 0.5 – 4.0 mg of polymer in 4 mL (at 140 °C) of stabilized TCB (same as mobile phase) and keeping for max. 3 hours at a maximum temperature of 160 °C with continuous gentle shaking prior sampling in into the GPC instrument.

As it is known in the art, the weight average molecular weight of a blend can be calculated if the molecular weights of its components are known according to:

$$Mw_b = \sum_i w_i \cdot Mw_i$$

where Mw_b is the weight average molecular weight of the blend,

w_i is the weight fraction of component “i” in the blend and

Mw_i is the weight average molecular weight of the component “i”.

The number average molecular weight can be calculated using the well-known mixing rule:

$$\frac{1}{Mn_b} = \sum_i \frac{w_i}{Mn_i}$$

where Mn_b is the weight average molecular weight of the blend,

w_i is the weight fraction of component “i” in the blend and

Mn_i is the weight average molecular weight of the component “i”.

Rheology

Rheological parameters such as Shear Thinning Index SHI and Viscosity are determined by using a rheometer, preferably a Anton Paar Physica MCR 300 Rheometer on compression moulded samples under nitrogen atmosphere at 190 °C using 25 mm diameter plates and plate and plate geometry with a 1.8 mm gap according to ASTM 1440-95. The oscillatory shear experiments were done within the linear viscosity range of strain at frequencies from 0.05 to 300 rad/s (ISO 6721-

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1). Five measurement points per decade were made. The method is described in detail in WO 00/22040.

The values of storage modulus (G'), loss modulus (G'') complex modulus (G^*) and complex viscosity (η^*) were obtained as a function of frequency (ω).

Shear thinning index (SHI), which correlates with MWD and is independent of M_w , was calculated according to Heino ("Rheological characterization of polyethylene fractions" Heino, E.L., Lehtinen, A., Tanner J., Seppälä, J., Neste Oy, Porvoo, Finland, Theor. Appl. Rheol., Proc. Int. Congr. Rheol, 11th (1992), 1, 360-362, and "The influence of molecular structure on some rheological properties of polyethylene", Heino, E.L., Borealis Polymers Oy, Porvoo, Finland, Annual Transactions of the Nordic Rheology Society, 1995.).

SHI value is obtained by calculating the complex viscosities at given values of complex modulus and calculating the ratio of the two viscosities. For example, using the values of complex modulus of 2.7 kPa and 210 kPa, then $\eta^*_{2.7}$ and $\eta^*(210 \text{ kPa})$ are obtained at a constant value of complex modulus of 2.7 kPa and 210 kPa, respectively. The shear thinning index $SHI_{2.7/210}$ is then defined as the ratio of the two viscosities $\eta^*_{2.7}$ and $\eta^*(210 \text{ kPa})$, i.e. $\eta(2.7)/\eta(210)$.

It is not always practical to measure the complex viscosity at a low value of the frequency directly. The value can be extrapolated by conducting the measurements down to the frequency of 0.126 rad/s, drawing the plot of complex viscosity vs. frequency in a logarithmic scale, drawing a best-fitting line through the five points corresponding to the lowest values of frequency and reading the viscosity value from this line.

Yellowness Index

Yellowness Index (YI) is a number calculated from spectrophotometric data that describes the change in colour of a test sample from clear or white towards yellow.

This test is most commonly used to evaluate colour changes in a material caused by real or simulated outdoor exposure. The spectrophotometric instrument is a Spectraflash SF600 with ColorTools software which calculate the yellowness index E 313 according to ASTM E313. On the sample holder and pipe sample is tested.

5 The yellowness index is rated as follows:

	Rating 1	Rating 2	Rating 3	Rating 4
YI according to ASTM E313	< (-0,9)	(-0 ,9) - 1,5	1,5 - 6,5	> 6,5

Ash Content

10 For ash content < 1000 ppm the so called "burning method" is employed.

- Heat up two clean platinum cups at 870°C for 15 minutes and afterwards cool them to room temperature in an desiccator

- Measure weight of the cups directly from the desiccator to 0.1 mg.

15 - Weight 15 g of polymer powder into the platinum cups (to 0.1 mg), (after sieving the powder).

- Burn up this powder in an burning device until all material has burnt, i.e. until flame dies.

- Place the cups in a burning oven at 870°C for 45 minutes.

20 - Cool the cups in an desiccator to room temperature and measure the weight of the cups to 0.1 mg.

- The weight of the ash content is the weight of the cup with ash content minus the weight of the empty cup.

- Ash content calculation: $(\text{gram ash}/\text{gram polymer sample}) \cdot 100 = \text{weight \% ash content}$

25 Irradiation of pipe

Polymer powders were compounded and pelletised in a Buss 100 mm machine.

Pipe extrusion was carried out in a Battenfeld extruder using a standard PE screw.

Melt temperature was in the range 200 to 230°C. Pipe dimensions were 20 x 2 mm (OD x S). Irradiation of pipes was carried out by electron beam at room temperature

30 in air using a dose of 160 kGy.

Degree of crosslinking, XL%

XL% was measured by decaline extraction (Measured according to ASTM D 2765-01, Method A)

5

Preparation Example 1

Preparation of the catalyst

10 The catalyst complex used in the polymerisation examples was bis(n-butylcyclopentadienyl) hafnium dibenzyl, $(n\text{-BuCp})_2\text{Hf}(\text{CH}_2\text{Ph})_2$, and it was prepared according to "Catalyst Preparation Example 2" of WO2005/002744, starting from bis(n-butylcyclopentadienyl) hafnium dichloride (supplied by Witco).

15 The catalyst preparation was made in a 160 L batch reactor into which a metallocene complex solution was added. Mixing speed was 40 rpm during reaction and 20 rpm during drying. Reactor was carefully flushed with toluene prior to reaction and purged with nitrogen after silica addition

Activated catalyst system

20 10.0 kg activated silica (commercial silica carrier, XPO2485A, having an average particle size 20 μm , supplier: Grace) was slurried into 21.7 kg dry toluene at room temperature. Then the silica slurry was added to 14.8 kg of 30 wt% methylalumoxane in toluene (MAO, supplied by Albemarle) over 3 hours. Afterwards the MAO/silica mixture was heated to 79°C for 6 hours and then cooled down to room temperature again.

25 The resulting solution was reacted with 0.33 kg of $(n\text{-BuCp})_2\text{Hf}(\text{CH}_2\text{Ph})_2$ in toluene (67.9 wt%) for 8 hours at room temperature.

The catalyst was dried under nitrogen purge for 5.5 hours at 50°C.

The obtained catalyst had an Al/Hf mol-ratio of 200, an Hf-concentration of 0.44 wt% and an Al-concentration of 13.2 wt%.

30

Preparation of catalyst 2

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Catalyst system is based on complex bis(n-butyl-cyclopentadienyl)hafnium dibenzyl (n-BuCp)₂HfBz₂. The catalyst system is prepared according to the principles disclosed in WO03/051934 as follow:

5 In a jacketed 90 dm³ glass-lined stainless steel reactor the complex solution was prepared at -5°C adding 1,26 kg of a 24,5 wt% PFPO ((2,2,3,3,4,4,5,5,6,6,7,7,8,8,9,9,9-heptadecafluorononyl)oxirane)/toluene solution very slowly (3.4 ml/min) to 20 kg 30wt% methylaluminumoxane/toluene solution. The temperature was increased to 25°C and the solution was stirred for 60 minutes. After addition of 253 g of complex (Hf-content 78,8 w% in toluene) the solution was
10 stirred for an additional two hours. That mixture was pumped at 5 l/h to the rotor stator with the rotor stator pair 4M. In the rotor stator with a tip speed of 4 m/s the mixture was mixed with a flow of 32 l/h of PFC (hexadecafluoro-1,3-dimethylcyclohexane) thus forming an emulsion. The droplets in the emulsion were solidified by an excess flow of 450 l/h PFC at a temperature of 60°C in a Teflon
15 hose. The hose was connected to a jacketed 160 dm³ stainless steel reactor equipped with a helical mixing element. In this reactor the catalyst particles were separated from the PFC by density difference. After the complex solution had been utilised the catalyst particles were dried in the 160 dm³ reactor at a temperature of 70°C and a nitrogen flow of 5 kg/h for 4 h.

20 The obtained catalyst had an Al/ Mt ratio of 300; Hf - content of 0,7 wt%; and an Al- content of 34,4 wt%.

Polymerisation Examples

Two-stage polymerisation

25 A loop reactor having a volume of 500 dm³ was operated at 85 °C and 58 bar pressure. Into the reactor were introduced propane diluent, hydrogen and ethylene. Polymerisation catalyst prepared according to the description above was introduced into the reactor continuously so as to achieve the productivities recited below.

30 The polymer slurry was withdrawn from the loop reactor and transferred into a flash vessel operated at 3 bar pressure and 70 °C temperature where the hydrocarbons were substantially removed from the polymer. The polymer was then introduced into a gas phase reactor operated at a temperature of 80°C and a pressure

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of 20 bar. In addition ethylene, hexene and hydrogen were introduced into the reactor. The conditions are shown in Table 1.

Table 1

		Polymer 1	Polymer 2
catalyst type	type	Cat 1	Cat 2
LOOP PREPOLY			
Temperature	°C	Not	80
Pressure	bar	in	63
catalyst feed	g/h	use	13
C ₂ feed	kg/h		2.0
H ₂ feed	g/h		1.3
C ₄ feed	g/h		31.5
LOOP			
Temperature	°C	85	80
Pressure	bar	58	58
C ₂ feed	kg/h	36	42
H ₂ feed (formier 25 %)	g/h	15.9	11.3
C ₂ concentration	mol-%	9.0	12.1
H ₂ /C ₂ ratio	mol/kmol	0.17	0.16
production rate	kg/h	31.0	33.6
MFR ₂	g/10min	9.3	8
density	kg/m ³	963	959
GPR			
temperature	°C	80	80
pressure	bar	20	20
C ₂ feed	kg/h	85.7	98.0
H ₂ feed (formier 25 %)	g/h	0.0	0.1
C ₆ feed	kg/h	1.6	1.3
C ₂ conc.	mol-%	55	50
H ₂ /C ₂ ratio	mol/kmol	0.12	0.11
C ₆ /C ₂ ratio	mol/kmol	6.0	4.0
C ₆ /C ₂ feed ratio	g/kg	18.7	12.9
split (mass balance)	wt-%	49	48.0

5

The polymers were received as powders. The properties of the formed polymers, and crosslinked pipe are reported in Table 2.

10

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Table 2

Designation	Polymer 1	Polymer 2
Density (kg/m ³)	946.5	943.4
$\eta^*_{0.05 \text{ rad/s}}$ (Pas)	18300	21400
$\eta^*_{5\text{kPA}}$ (Pas)	16200	18700
MFR ₂₁ (g/10min)	14	13
MFR ₅ (g/10min)	1.5	1.4
M _w (g/mol)	157000	165000
M _n (g/mol)	33900	38700
M _w /M _n	4.6	4.3
SHI _{5/300}	6.1	6.2
SHI _{2.7/210}	4.7	4.9
Surface quality	Good	Good
XL, % (irrad 160 kGy)	>62	>60
Ash Content (ppm)	300	190

5 Low catalyst activity is obviously not desirable from a process economy point of view and neither from a product quality point of view as it leads to high ash contents in the polymer. High ash contents leads to undesirable feature such as yellowness, gels etc. Table 3 shows that ash content should be kept below a range between 250-500 ppm.

Table 3. Yellowness index vs. ash content for SSC resins in the form of pipes

10

Yellowness index	Ash content (ppm)
1	<250
3	540
4	710
4	1680
4	2765

Claims

1. A cross-linked polyethylene comprising a multimodal ethylene polymer with a density of less than 950 kg/m^3 obtained by polymerisation with a single-site catalyst and
5 having
an MFR₂₁ in the range of 10 to 20 g/10min;
a shear thinning index SHI_{2.7/210} of at least 4; which has been cross-linked.
2. A cross-linked polyethylene as claimed in claim 1 comprising a multimodal
10 ethylene polymer having a density is in the range of 940 to less than 950 kg/m^3 .
3. A cross-linked polyethylene as claimed in claim 1 or 2 comprising a multimodal ethylene polymer having an ash content of less than 350 ppm.
- 15 4. A cross-linked polyethylene as claimed in any one of claims 1 to 3 comprising a multimodal ethylene polymer having a cross-linkability of at least 60% measured by decaline extraction (according to ASTM D 2765-01, Method A).
- 20 5. A cross-linked polyethylene as claimed in any one of claims 1 to 4 comprising a multimodal ethylene polymer having a lower molecular weight ethylene homopolymer component and a higher molecular weight ethylene copolymer component.
- 25 6. A cross-linked polyethylene as claimed in any one of claims 1 to 5 comprising a multimodal ethylene polymer having a lower molecular weight ethylene homopolymer component and a higher molecular weight ethylene hexene copolymer component.
7. A cross-linked polyethylene as claimed in any one of claims 1 to 6 comprising a multimodal ethylene polymer having an M_w/M_n of at least 4.

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8. A cross-linked polyethylene as claimed in any one of claims 1 to 7 having a cross-linking degree of at least 60%.
9. A cross-linked pipe comprising a cross-linked polyethylene as claimed in any one of claims 1 to 8.
10. A cross-linked pipe as claimed in claim 9 cross-linked by irradiation.
11. A cross-linked pipe according to claim 10 wherein said pipe has a degree of cross-linking of at least 60%.
12. A process for the preparation of a crosslinked multimodal ethylene polymer comprising:
- (I) polymerising ethylene and optionally at least one comonomer in a first stage in the presence of a single site catalyst;
- (II) polymerising ethylene and optionally at least one comonomer in a second stage in the presence of the same single site catalyst; and crosslinking the resulting polymer so as to form a cross-linked ethylene polymer as claimed in any one of claims 1 to 8.
13. A process as claimed in claim 12 wherein said single site catalyst is supported on silica or is a solid catalyst formed from by solidification of catalyst droplets dispersed in a continuous phase.
14. A multimodal ethylene polymer with a density in the range of 940 to less than 950 kg/m³ obtained by polymerisation with a single-site catalyst and having an MFR₂₁ in the range of 10 to 20 g/10min;

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a shear thinning index $SHI_{2.7/210}$ of at least 4; having a lower molecular weight ethylene homopolymer component and a higher molecular weight ethylene copolymer component.

5 15. A polymer composition comprising a multimodal ethylene polymer as claimed in claim 14 and at least one additive and/or other olefinic component.

16. Use of a multimodal ethylene polymer with a density of less than 950 kg/m^3 obtained by polymerisation with a single-site catalyst and having
10 an MFR_{21} in the range of 10 to 20 g/10min;
a shear thinning index $SHI_{2.7/210}$ of at least 4 in the manufacture of a cross-linked pipe.

17. A cross-linked pipe comprising a cross-linked polyethylene as claimed in any
15 one of claims 1 to 9 with a density of less than 950 kg/m^2 obtained by polymerisation with a single site catalyst and having
an MFR_{21} in the range of 10-20 g/10min;
a shear thinning index $SHI_{2.7/210}$ of at least 4; having a lower molecular weight ethylene homopolymer component and a higher molecular weight ethylene copolymer
20 component.