

FLUOROPOLYMER FOR MAKING A FLUOROELASTOMER

Field of the invention

5 This invention relates to amorphous fluoropolymers, i.e. amorphous polymers having a fluorinated backbone. The amorphous fluoropolymers are curable and can be cured to obtain a fluoroelastomer. In particular, the present invention relates to such fluoropolymers having desirable processing characteristics, e.g. in their extrusion into articles such as tubes and in injection molding articles.

Background of the invention

10 Fluoropolymers have been long known and have been used in a variety of applications because of several desirable properties such as heat resistance, chemical resistance, weatherability, UV-stability etc... The various applications of fluoropolymers are for example

15 described in "Modern Fluoropolymers", edited by John Scheirs, Wiley Science 1997.

Fluoropolymers include homo and co-polymers of a gaseous fluorinated olefin such as tetrafluoroethylene (TFE), chlorotrifluoroethylene (CTFE) and/or vinylidene fluoride (VDF) with one or more comonomers such as for example hexafluoropropylene (HFP) or perfluorovinyl ethers (PVE) or non-fluorinated olefins such as ethylene (E) and propylene (P).

20 Fluoropolymers include melt-processible and non-melt-processible polymers. For example, polytetrafluoroethylene and copolymers of tetrafluoroethylene with small amounts (e.g. not more than 0.5% by weight) of a comonomer are generally not melt-processible with conventional equipment used for the processing of thermoplastic polymers because of their

25 high molecular weight and their high melt viscosity. Accordingly, for these non-melt-processible fluoropolymers, special processing techniques have been developed to allow forming these fluoropolymers into desired articles and shapes.

Melt-processible thermoplastic fluoropolymers are also known and these can be obtained from

30 various combinations of fluorinated and/or non-fluorinated monomers. As they are melt-processible, they can be processed with equipment typically used for the processing, of thermoplastic polymers, such as e.g. molding or extrusion. Melt-processible thermoplastic fluoropolymers include generally amorphous fluoropolymers and fluoropolymers that have

substantial crystallinity. Fluoropolymers that are generally amorphous are typically used to make fluoroelastomers by curing or vulcanizing the fluoropolymer. Although, the elastomeric properties generally are obtained after curing, the fluoropolymers used for making the fluoroelastomer are often also called fluoroelastomer. Melt-processible thermoplastic fluoropolymers that have substantial crystallinity and that accordingly have a clearly detectable and prominent melting point are known in the art as fluorothermoplasts. They typically have a melting point between 100°C and 320°C depending on their monomer composition.

Amorphous fluoropolymers may be cured by providing cure-sites in the amorphous fluoropolymer which can then react with one or more components of the cure composition to provide a three dimensional cross-linking network. Typically, the cure-sites comprise a halogen such as bromine or iodine that is capable of participating in a peroxide cure reaction or the cure-sites may comprise a nitrile group that can also be cured with a peroxide or other cure components. Alternatively, the amorphous fluoropolymer can be dehydrofluorinated to form cure sites that can then be involved in a cure reaction. Such amorphous fluoropolymers are partially fluorinated, i.e. they contain carbon-hydrogen bonds in the backbone, and are known in the art as bisphenol curable fluoropolymers.

Peroxide curable amorphous fluoropolymers have been disclosed in a variety of publications. For example EP 398241 discloses a fluoropolymer that can be obtained by continuous emulsion polymerization in the presence of an iodinated compound. The fluoropolymer so produced contains at least 0.1% by weight of iodine. The fluoropolymer further comprises repeating units having bromine such that the amount of bromine in the polymer is between 0.1 and 1% by weight.

EP 171290 discloses a peroxide curable fluoropolymer that comprises repeating units of an iodine containing monomer. The repeating units are contained in the polymer in an amount of 0.1 to 2 mole %. It is taught that such fluoropolymers cure faster and have a better compression set compared to analogues fluoropolymers having bromine containing repeating units. It is also taught that the fluoropolymers have a lower viscosity than the bromine containing analogues, which would present a processing advantage.

Bromine containing peroxide curable fluoropolymers are taught in US 4214060 and EP 211251. The latter patent teaches a fluoropolymer that comprises repeating units derived from a brominated perfluorovinyl monomer of the formula $\text{CF}_2\text{Br}-(\text{R}_f)_n-\text{O}-\text{CF}=\text{CF}_2$, wherein R_f is fluorinated alkylene and n is 0 or 1. The polymer is produced in the presence of a chain transfer agent of the formula $\text{R}-(\text{CF}_2\text{Br})_m$ where m is 1 or 2. It is taught that by using such chain transfer agent, the possibility of branching of the fluoropolymer chain can be kept to a minimum as compared to other bromine containing chain transfer agents.

The amorphous fluoropolymers are typically used in making a variety of elastomeric articles including for example tubes, gaskets, O-rings etc. In producing the elastomeric article, a curable elastomer composition comprising the amorphous fluoropolymer and a cure composition may be extruded or injection molded. A desire still exists to improve the processing behaviour of the amorphous fluoropolymer in extrusion and in particular in injection molding. For example, problems may arise in filling of the mold in injection molding, particularly at high rates.

Summary of the invention

It is desirable to improve the processing characteristics of amorphous fluoropolymers in particular in extrusion and injection molding. It would in particular be desirable to improve the critical shear strength and melt tension to improve the processing in tube extrusion. It would further be desired that such improvement of the processing properties does not adversely affect the curing of the fluoropolymer to obtain a fluoroelastomer and the resulting mechanical and physical properties of the fluoroelastomer obtained. It is generally also desirable that the fluoropolymers can be produced in an easy and convenient way and in an environmentally friendly way.

In accordance with one aspect of the invention, there is provided an amorphous fluoropolymer wherein the amorphous fluoropolymer (i) has one or more cure site components, the cure site components being contained in the amorphous fluoropolymer in an amount between 0.1 and 0.5 mole % based on the total amount of repeating units or (ii) is capable of being dehydrofluorinated, wherein the amorphous fluoropolymer is derivable from a polymerization of (a) one or more gaseous fluorinated monomers and (b) not more than 0.5% by weight based on the total weight of monomers of one or more olefins having a bromine or iodine atom

bonded to a carbon of the double bond of the olefin or (iii) has some combination of (i) and (ii).

It has been found that the amorphous fluoropolymers according to the invention have improved processing characteristics, in particular in injection molding and extrusion. For example, the fluoropolymers have an improved critical shear rate, i.e. the rate at which melt fracture occurs in the extrusion of the fluoropolymer. Furthermore, it has been found that the amorphous fluoropolymers have good cure characteristics and the resulting elastomers have good mechanical and physical properties.

In a further aspect of the present invention a method of producing the fluoropolymer is provided. The method comprises polymerizing (a) one or more gaseous fluorinated monomers and (b) not more than 0.5% by weight based on the total weight of monomers of one or more olefins having a bromine or iodine atom bonded to a carbon of the double bond of the olefin and providing capability for the fluoropolymer to be cured by (i) polymerizing the one or more gaseous fluorinated monomers in the presence of one or more components comprising a cure site, the total amount of said components being sufficient for introducing between 0.1 and 0.5 mole % based on the total amount of repeating units of cure site components in the amorphous fluoropolymer or (ii) selecting at least one partially fluorinated gaseous monomer as said one or more gaseous fluorinated monomers or copolymerizing said gaseous fluorinated monomers with one or more non-fluorinated comonomers or partially fluorinated non-gaseous monomers so as to provide an amorphous fluoropolymer capable of being dehydrofluorinated.

In a still further aspect, the invention provides a curable composition for making a fluoroelastomer. The composition comprises an amorphous fluoropolymer as defined above and a cure composition comprising one or more components for curing the amorphous fluoropolymer. The invention also provides a method of making an elastomer article comprising injection molding or extruding the curable composition and curing said curable composition.

The term "copolymer" in connection with the present invention should generally be understood to mean a polymer comprising repeating units derived from the recited monomers

without excluding the option of other further repeating units being present that derive from other monomers not explicitly recited. Accordingly, for example the term 'copolymer of monomers A and B' includes binary polymers of A and B as well as polymers that have further monomers other than A and B such as for example terpolymers.

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Detailed description of the invention

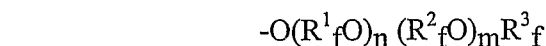
According to the present invention, the amorphous fluoropolymer is derivable from polymerizing (a) one or more gaseous fluorinated monomers and (b) not more than 0.5% by weight based on the total weight of monomers of one or more olefins having a bromine or iodine atom bonded to a carbon of the double bond of the olefin. The olefin may apart from containing Br and/or I atoms, be non-fluorinated, i.e. not contain fluorine atoms, may be partially fluorinated, i.e. some but not all hydrogen atoms have been replaced with fluorine atoms, or the olefin may be a perfluorinated compound in which all hydrogen atoms have been replaced with fluorine atoms except for those replaced with I or Br.

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In a particular embodiment, the olefin corresponds to the general formula:



wherein each X may be the same or different and is selected from the group consisting of hydrogen, F, Cl, Br and I, with the proviso that at least one X represents Br or I, Z represents hydrogen, F, Cl, Br, I, a perfluoroalkyl group, a perfluoroalkoxy group or a perfluoropolyether group. Examples of perfluoroalkyl groups include linear or branched perfluoroalkyl groups having between 1 and 8 carbon atoms, for example 1 to 5 carbon atoms. Examples of perfluoroalkoxy groups include those that have between 1 and 8 carbon atoms, for example between 1 and 5 carbon atoms in the alkyl group and whereby the alkyl group may be linear or branched. Examples of perfluoropolyether groups include those corresponding to the formula:



wherein R^1_f and R^2_f are each linear or branched perfluoroalkylene groups of 1 to 6 carbon atoms, in particular 2 to 6 carbon atoms, m and n are independently 0 to 10 with m+n being at least 1 and R^3_f is a perfluoroalkyl group of 1 to 6 carbon atoms.

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In a particular embodiment, olefins of formula (I) can be employed wherein X is selected from hydrogen, F and Br with the proviso that at least one X represents Br and Z is hydrogen, F, Br, a perfluoroalkyl group or a perfluoroalkoxy group. Specific examples of olefins that may

conveniently be used include 1-bromo-1,2,2,-trifluoroethylene, bromotrifluoroethylene (referred as BTFE), vinylbromide, 1,1-dibromoethylene, 1,2-dibromoethylene and 1-bromo-2,3,3,3-tetrafluoro-propene. Generally preferred is 1-bromo-2,2-difluoroethylene (BDFE).

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The use of the aforementioned olefin in preparation of the amorphous fluoropolymers causes the polymer to become a non-linear polymer i.e. branched polymer. The level of branching or non-linearity can be characterized through the long chain branching index (LCBI). The LCBI can be determined as described in R. N. Shroff, H. Mavridis; *Macromol.*, **32**, 8454-8464

10 (1999) & **34**, 7362-7367 (2001) according to the equation:

$$LCBI = \frac{\eta_{0,br}^{1/a}}{[\eta]_{br}} \cdot \frac{1}{k^{1/a}} - 1 \quad \text{eq. 1}$$

In the above equation, $\eta_{0,br}$ is the zero shear viscosity (units Pa's) of the branched fluoropolymer measured at a temperature T and $[\eta]_{br}$ is the intrinsic viscosity (units ml/g) of the branched fluoropolymer at a temperature T' in a solvent in which the branched fluoropolymer can be dissolved and a and k are constants. These constants are determined from the following equation:

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$$\eta_{0,lin} = k \cdot [\eta]_{lin}^a \quad \text{eq. 2}$$

wherein $\eta_{0,lin}$ and $[\eta]_{lin}$ represent respectively the zero shear viscosity and intrinsic viscosity of the corresponding linear fluoropolymer measured at the respective same temperatures T and T' and in the same solvent. Thus, the LCBI is independent of the selection of the measurement temperatures and solvent chosen provided of course that the same solvent and temperatures are used in equations 1 and 2. The zero shear viscosity and intrinsic viscosity are typically determined on freeze coagulated fluoropolymers.

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The values a and k along with the test conditions for some of the fluoropolymers that may be used in the melt-processible polymer composition are set forth in the following table:

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Polymer	test condition	a-value	k-value
TFE ₃₉ /HFP ₁₁ /VDF ₅₀	A	5.8	2.4 10 ⁻⁸
TFE _{24.5} /HFP ₂₃ /VDF _{52.5}	A	5.8	5.5 10 ⁻⁸
VDF ₇₈ /HFP ₂₂	A	5.8	1.5 10 ⁻⁸
polyvinylidene fluoride	B	5.8	1.2 10 ⁻⁸

polyvinylidene fluoride	C	5.8	$2.2 \cdot 10^{-8}$
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In the above table, the indexes to the monomer units in the polymer indicate the amount of the respective unit in mole % and the test conditions are as follows:

A: shear viscosity at 265°C and the intrinsic viscosity in methyl ethyl ketone at 35°C

5 B: shear viscosity at 230°C and the intrinsic viscosity in dimethylformamide at 23°C

C: shear viscosity at 230°C and the intrinsic viscosity in dimethylformamide at 110°C.

It can be observed from the above table that the constant A appears to be independent of the fluoropolymer tested whereas the k-value varies with composition of the fluoropolymer and test condition used.

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The LCBI of the amorphous fluoropolymer can be influenced by the nature and amount of olefin used. Generally it will be desired to obtain amorphous fluoropolymers that have an LCBI of at least 0.1. For example, in one embodiment, the LCBI is at least 0.5, in another embodiment the LCBI may be at least 1 and in a still further embodiment, the LCBI is at least 15 1.5. It has generally been observed that for a given molecular weight of the fluoropolymer, the critical shear rate improves with an increase in the LCBI. However, the LCBI should not be too high as this may cause the fluoropolymer to have substantial amount of gel fractions which may again impair the processing and/or ultimate properties of the fluoroelastomer. Typically, the LCBI should be between 0.1 and 3. To generally achieve the desired LCBI, the olefin 20 having a bromine or iodine atom on the double bond should be used in amounts of not more than 0.5% by weight based on the total weight of the monomers used to produce the fluoropolymer. Typical amounts of the olefin are between 0.01% by weight and 0.4% by weight. In a particular embodiment, the amount is between 0.05 and 0.35% by weight.

25 The fluoropolymers can be obtained with any of the known polymerization techniques including solution polymerization and suspension polymerization. The fluoropolymers are generally made through an aqueous emulsion polymerization process, which can be conducted in a known manner. The reactor vessel for use in the aqueous emulsion polymerization process is typically a pressurizable vessel capable of withstanding the internal pressures 30 during the polymerization reaction. Typically, the reaction vessel will include a mechanical agitator, which will produce thorough mixing of the reactor contents and heat exchange system. Any quantity of the fluoromonomer(s) may be charged to the reactor vessel. The

monomers may be charged batchwise or in a continuous or semicontinuous manner. By semi-continuous is meant that a plurality of batches of the monomer are charged to the vessel during the course of the polymerization. The independent rate at which the monomers are added to the kettle will depend on the consumption rate of the particular monomer with time.

- 5 Preferably, the rate of addition of monomer will equal the rate of consumption of monomer, i.e. conversion of monomer into polymer.

The reaction kettle is charged with water, the amounts of which are not critical. To the aqueous phase there is generally also added the fluorinated surfactant, typically a non-telogenic fluorinated surfactant. The polymerization may also be carried out without addition
10 of a fluorinated surfactant. The fluorinated surfactant when used, is typically used in amount of 0.01% by weight to 1% by weight. Suitable fluorinated surfactants include any fluorinated surfactant commonly employed in aqueous emulsion polymerization. Particularly preferred fluorinated surfactants are those that correspond to the general formula:



wherein Y represents hydrogen, Cl or F; R_f represents a linear or branched perfluorinated alkylene having 4 to 10 carbon atoms; Z represents COO^- or SO_3^- and M represents an alkali metal ion or an ammonium ion. Most preferred fluorinated surfactants for use in this invention are the ammonium salts of perfluorooctanoic acid and perfluorooctane sulphonic acid.

- 20 Mixtures of fluorinated surfactants can be used.

A chain transfer agent can be used in the polymerization to control the molecular weight of the fluoropolymer. The chain transfer agent is typically charged to the reaction kettle prior to the initiation of the polymerization. Useful chain transfer agents include C_2 - C_6 hydrocarbons
25 such as ethane, alcohols, ethers, esters including aliphatic carboxylic acid esters and malonic esters, ketones and halocarbons. Particularly useful chain transfer agents are dialkylethers such as dimethyl ether and methyl tertiary butyl ether. Further additions of chain transfer agent in a continuous or semi-continuous way during the polymerization may also be carried out. For example, a fluoropolymer having a bimodal molecular weight distribution is
30 conveniently prepared by first polymerizing fluorinated monomer in the presence of an initial amount of chain transfer agent and then adding at a later point in the polymerization further chain transfer agent together with additional monomer.

The polymerization is usually initiated after an initial charge of monomer by adding an initiator or initiator system to the aqueous phase. For example peroxides can be used as free radical initiators. Specific examples of peroxide initiators include, hydrogen peroxide, diacylperoxides such as diacetylperoxide, dipropionylperoxide, dibutylperoxide, 5 dibenzoylperoxide, benzoylacetylperoxide, diglutaric acid peroxide and dilaurylperoxide, and further water soluble per-acids and water soluble salts thereof such as e.g. ammonium, sodium or potassium salts. Examples of per-acids include peracetic acid. Esters of the per-acid can be used as well and examples thereof include tert.-butylperoxyacetate and tert.-butylperoxypivalate. A further class of initiators that can be used are water soluble azo- 10 compounds. Suitable redox systems for use as initiators include for example a combination of peroxodisulphate and hydrogen sulphite or disulphite, a combination of thiosulphate and peroxodisulphate or a combination of peroxodisulphate and hydrazine. Further initiators that can be used are ammonium- alkali- or earth alkali salts of persulfates, permanganic or manganic acid or manganic acids. The amount of initiator employed is typically between 0.03 15 and 2% by weight, preferably between 0.05 and 1% by weight based on the total weight of the polymerization mixture. The full amount of initiator may be added at the start of the polymerization or the initiator can be added to the polymerization in a continuous way during the polymerization until a conversion of 70 to 80%. One can also add part of the initiator at the start and the remainder in one or separate additional portions during the polymerization. 20 Accelerators such as for example water-soluble salts of iron, copper and silver may preferably also be added.

During the initiation of the polymerization reaction, the sealed reactor kettle and its contents are conveniently pre-heated to the reaction temperature. Polymerization temperatures are from 25 20°C to 150°C, particularly from 30°C to 110°C and more specifically from 40°C to 100°C. The polymerization pressure is typically between 4 and 30 bar, in particular 8 to 20 bar. The aqueous emulsion polymerization system may further comprise auxiliaries, such as buffers and complex-formers.

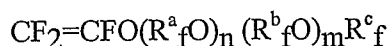
30 The amount of polymer solids that can be obtained at the end of the polymerization is typically between 10% and 45% by weight, preferably between 20% and 40% by weight and the average particle size of the resulting fluoropolymer is typically between 50 nm and 500 nm.

The (aqueous emulsion) polymerization process comprises the polymerization of one or more gaseous fluorinated monomer which may be perfluorinated or not. Examples of a gaseous fluorinated monomer include tetrafluoroethylene (TFE), chlorotrifluoroethylene, vinylidene fluoride (VDF), perfluoroalkyl vinyl monomers such as hexafluoropropylene (HFP),
 5 fluorinated allyl ethers, in particular perfluorinated allyl ethers and fluorinated vinyl ethers, in particular perfluorovinyl ethers such as perfluoromethyl vinyl ether. The use of a partially fluorinated gaseous monomer can provide a fluoropolymer that is capable of dehydrofluorination. For example VDF is particularly suitable to provide a fluoropolymer capable of dehydrofluorination. Comonomers that can be used for copolymerization with the
 10 gaseous fluorinated monomers include non-gaseous fluorinated monomers, i.e. fluorinated monomers that under the conditions of polymerization are in a liquid phase and non-fluorinated monomers such as ethylene and propylene. If a fluoropolymer capable of dehydrofluorination is desired and perfluorinated gaseous monomers are being used, then the comonomer should be partially fluorinated or non-fluorinated to provide for the
 15 dehydrofluorination capability of the fluoropolymer.

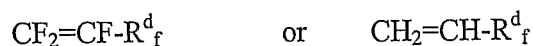
Examples of perfluorovinyl ethers that can be used in the process of the invention include those that correspond to the formula:



20 wherein R_f represents a perfluorinated aliphatic group that may contain one or more oxygen atom. Particularly preferred perfluorinated vinyl ethers correspond to the formula:



wherein R^a_f and R^b_f are different linear or branched perfluoroalkylene groups of 1 to 6 carbon atoms, in particular 2 to 6 carbon atoms, m and n are independently 0 to 10 and R^c_f is a
 25 perfluoroalkyl group of 1 to 6 carbon atoms. Specific examples of perfluorinated vinyl ethers include perfluoro methyl vinyl ether (PMVE), perfluoro n-propyl vinyl ether (PPVE-1), perfluoro-2-propoxypropylvinyl ether (PPVE-2), perfluoro-3-methoxy-n-propylvinyl ether, perfluoro-2-methoxy-ethylvinyl ether and
 $\text{CF}_3-(\text{CF}_2)_2-\text{O}-\text{CF}(\text{CF}_3)-\text{CF}_2-\text{O}-\text{CF}(\text{CF}_3)-\text{CF}_2-\text{O}-\text{CF}=\text{CF}_2$. Some of the aforementioned
 30 perfluorovinyl ethers will be liquid under the conditions of polymerization and are thus non-gaseous fluorinated monomers. Suitable perfluoroalkyl vinyl monomers correspond to the general formula:



wherein R_f^d represents a perfluoroalkyl group of 1 to 10, preferably 1 to 5 carbon atoms. A typical example of a perfluoroalkyl vinyl monomer is hexafluoropropylene.

The olefin used in the invention to introduce branching may be added to the polymerization vessel in portions or in a continuous way. The olefin may be fed to the polymerization from a separate inlet or storage cylinder. Alternatively, a mixture of the olefin with a fluorinated monomer may be used to feed the olefin to the polymerization. The latter method may provide improved homogeneous incorporation of the olefin into the polymer leading to a more uniform distribution of long chain branches. Suitable fluorinated monomers with which the olefin can be admixed to feed to the polymerization include fluorinated olefins such as CTFE, HFP and perfluorovinyl ethers such as perfluoromethyl vinyl ether.

In one embodiment of the invention, the amorphous fluoropolymer includes a cure site component. The cure site component is generally present in an amount of 0.1 to 0.5 mole %. According to a particular embodiment, the amount of cure site component is between 0.15 and 0.4 mole % or between 0.2 and 0.3 mole % based on the total amount of repeating units in the fluoropolymer. To introduce a cure site component into the amorphous fluoropolymer, a monomer comprising the particular cure-site may be used or the polymerization may be conducted by using a chain transfer agent or initiator that is capable of introducing the cure site at the terminal ends of the polymer chain.

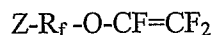
For example, in order to introduce halogens, which are capable of participation in the peroxide cure reaction, along the chain, the copolymerization of the basic monomers of the fluoropolymer may be carried out with a suitable fluorinated cure-site monomer. The cure-site monomer is typically an ethylenically unsaturated monomer that does not have Br or I atoms on the double bond. Examples of comonomers include those that correspond to the formula:



wherein each X independently represents H, F or Cl, R_f represents a perfluorinated aliphatic group that may contain one or more oxygen atoms and Z represents Br or I.

Further examples of comonomers can be selected for instance from:

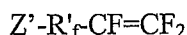
(a) bromo- or iodo- (per)fluoroalkyl-perfluorovinylethers having the formula:



- 5 wherein Z is Br or I, R_f is a (per)fluoroalkylene C_1 to C_{12} , optionally containing chlorine and/or ether oxygen atoms; for example: $BrCF_2-O-CF=CF_2$, $BrCF_2CF_2-O-CF=CF_2$, $BrCF_2CF_2CF_2-O-CF=CF_2$, $CF_3CFBrCF_2-O-CF=CF_2$, and the like;

(b) bromo- or iodo (per)fluoroolefins such as those having the formula:

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wherein Z' is Br or I, R'_f is a (per)fluoroalkylene C_1 to C_{12} , optionally containing chlorine atoms; for instance: 4-bromo-perfluorobutene-1, or 4-bromo-3,3,4,4-tetrafluorobutene-1;

- 15 (c) non-fluorinated bromo- olefins such as 4-bromo-1-butene.

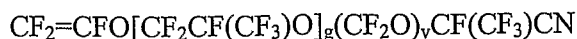
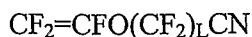
In replacement of or in addition to the cure site comonomer, the fluoropolymer can contain a cure site component in terminal position, deriving from a suitable chain transfer agent introduced in the reaction medium during the polymer preparation, as described in U.S. Pat. No. 4,501,869 or derived from a suitable initiator. Examples of useful initiators include $X(CF_2)_nSO_2Na$ with $n=1$ to 10 (where X is Br or I) or an initiator composition comprising ammonium persulfate and potassium bromide.

- 25 Examples of chain transfer agents include those having the formula R_fBr_x , wherein R_f is a x-valent (per)fluoroalkyl radical C_1 to C_{12} , optionally containing chlorine atoms, while x is 1 or 2. Examples include CF_2Br_2 , $Br(CF_2)_2Br$, $Br(CF_2)_4Br$, CF_2ClBr , $CF_3CFBrCF_2Br$, and the like. Further examples of suitable chain transfer agents are disclosed in US 4,000,356.

- 30 Alternatively, or additionally, the fluoropolymer may comprise cure site components that have a nitrile group. To introduce such nitrile containing cure site components, a nitrile group containing cure site monomer may be used in the polymerization process. In one embodiment useful nitrile group-containing cure site monomers include nitrile-containing fluorinated olefins and nitrile-containing fluorinated vinyl ethers, such as depicted below:



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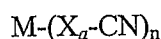


where, in reference to the above formulas: $L=2$ to 12 ; $g=0$ to 4 ; $k=1$ to 2 ; $v=0$ to 6 ; and $u=1$ to 4 , R_f is a perfluoroalkylene or a bivalent perfluoroether group. Representative examples of such a monomer include perfluoro(8-cyano-5-methyl-3,6-dioxo-1-octene), $\text{CF}_2=\text{CFO}(\text{CF}_2)_5\text{CN}$, and $\text{CF}_2=\text{CFO}(\text{CF}_2)_3\text{OCF}(\text{CF}_3)\text{CN}$.

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Nitrile groups may also be introduced in the fluoropolymer at the terminal ends by initiating the polymerization in the presence of a nitrile group containing salt or pseudohalogen. Suitable nitrile group containing salts include those that have the nitrile group in the anion of the salt and in particular correspond to the formula:

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wherein M represents a mono- or multi-valent cation including a metal cation or an ammonium, X is O, S, Se or N, α has a value of 0 or 1 and n corresponds to the valence of the cation. Suitable cations M include organic (e.g. tetraalkylammonium cations) and inorganic cations. Particularly useful cations are ammonium and metal cations including mono-valent cations such as sodium and potassium as well as divalent cations such as calcium and magnesium. Examples of potassium salts include potassium cyanide, potassium cyanate and potassium thiocyanate. The salts wherein X is O or S and the cyanides are generally preferred.

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Examples of fluoropolymers that may be produced with the process according to the invention include a copolymer of tetrafluoroethylene and hexafluoropropylene, a copolymer of tetrafluoroethylene and perfluorovinyl ether (e.g. PMVE, PPVE-1, PPVE-2 or a combination of PPVE-1 and PPVE-2), a copolymer of vinylidene fluoride and hexafluoropropylene, a copolymer of tetrafluoroethylene and vinylidene fluoride, a copolymer of chlorotrifluoroethylene and vinylidene fluoride, a copolymer of tetrafluoroethylene and ethylene, a copolymer of tetrafluoroethylene and propylene, a copolymer of vinylidene fluoride and perfluorovinyl ether (e.g. PMVE, PPVE-1, PPVE-2 or a combination of PPVE-1 and PPVE-2), a terpolymer of tetrafluoroethylene, hexafluoropropylene and perfluorovinyl ether (e.g. PMVE, PPVE-1, PPVE-2 or a combination of PPVE-1 and PPVE-2), a terpolymer of tetrafluoroethylene, ethylene or propylene and perfluorovinyl ether (e.g. PMVE, PPVE-1,

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PPVE-2 or a combination of PPVE-1 and PPVE-2), a terpolymer of tetrafluoroethylene, ethylene or propylene and hexafluoropropylene, a terpolymer of tetrafluoroethylene, vinylidene fluoride and hexafluoropropylene, a terpolymer of vinylidene fluoride, tetrafluoroethylene and perfluorovinyl ether (e.g. PMVE, PPVE-1, PPVE-2 or a combination
5 of PPVE-1 and PPVE-2), and a copolymer of a copolymer of tetrafluoroethylene, ethylene or propylene, hexafluoropropylene and perfluorovinyl ether (e.g. PMVE, PPVE-1, PPVE-2 or a combination of PPVE-1 and PPVE-2). Any of the aforementioned copolymers may additionally contain a cure site component deriving from a cure-site comonomer and/or from an initiation system or chain transfer agent as described above.

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A curable fluoroelastomer composition in accordance with the present invention comprises the amorphous fluoropolymer and a cure composition for curing the amorphous fluoropolymer. The cure composition will of course depend on whether or not the amorphous fluoropolymer can be dehydrofluorinated and whether or not the fluoropolymer includes cure site
15 components as well as the nature thereof.

20

In case the fluoropolymer includes a cure site component such as a halogen or a nitrile, the cure composition may comprise one or more peroxides. Suitable organic peroxides are those which generate free radicals at curing temperatures. A dialkyl peroxide or a bis(dialkyl
peroxide) which decomposes at a temperature above 50° C is especially preferred. In many cases it is preferred to use a di-tertiarybutyl peroxide having a tertiary carbon atom attached to peroxy oxygen. Among the most useful peroxides of this type are 2,5-dimethyl-2,5-
di(tertiarybutylperoxy)hexyne-3 and 2,5-dimethyl-2,5- di(tertiarybutylperoxy)hexane. Other peroxides can be selected from such compounds as dicumyl peroxide, dibenzoyl peroxide,
25 tertiarybutyl perbenzoate, α,α' -bis(t-butylperoxy)-diisopropylbenzene), and di[1,3-dimethyl-3-(t-butylperoxy)-butyl]carbonate. Generally, about 1 to 3 parts of peroxide per 100 parts of fluoropolymer is used.

30

Another component which is usually included in a cure composition based on an organic peroxide, is a coagent composed of a polyunsaturated compound which is capable of cooperating with the peroxide to provide a useful cure. These coagents can be added in an amount equal to 0.1 and 10 parts per hundred parts fluoropolymer, preferably between 2 to 5 parts per hundred parts fluoropolymer. Examples of useful coagents include triallyl cyanurate; triallyl isocyanurate; triallyl trimellitate; tri(methylallyl) isocyanurate; tris(diallylamine)-s-

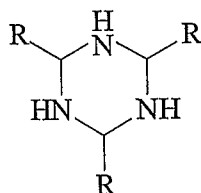
triazine; triallyl phosphite; N,N-diallyl acrylamide; hexaallyl phosphoramidate; N,N,N',N'-tetraallyl tetraphthalamide; N,N,N',N'-tetraallyl malonamide; trivinyl isocyanurate; 2,4,6-trivinyl methyltrisiloxane; N,N'-m-phenylenebismaleimide; diallyl-phthalate and tri(5-norbornene-2-methylene)cyanurate. Particularly useful is triallyl isocyanurate. Other useful
 5 coagents include the bis-olefins, for instance, those disclosed in EPA 0 661 304 A1, EPA 0 784 064 A1 and EPA 0 769 521 A1.

Further, if the cure site component comprises a nitrile, any of the cure composition suitable for curing nitrile components can be used. For example, such nitrile cure composition may
 10 comprise one or more ammonia-generating compounds. "Ammonia-generating compounds" include compounds that are solid or liquid at ambient conditions but that generate ammonia under conditions of cure. Such compounds include, for example, hexamethylene tetramine (urotropin), dicyan diamide, and metal-containing compounds of the formula:



15 where A^{w+} is a metal cation such as Cu^{2+} , Co^{2+} , Co^{3+} , Cu^+ , and Ni^{2+} ; w is equal to the valence of the metal cation; Y^{w-} is a counterion, typically a halide, sulfate, nitrate, acetate or the like; and v is an integer from 1 to about 7.

Also useful as ammonia-generating compounds are substituted and unsubstituted triazine
 20 derivatives such as those of the formula:



wherein R is a hydrogen or a substituted or unsubstituted alkyl, aryl, or aralkyl group having from 1 to about 20 carbon atoms. Specific useful triazine derivatives include hexahydro-
 25 1,3,5-s-triazine and acetaldehyde ammonia trimer.

Alternatively, or additionally, the amorphous fluoropolymer may be capable of dehydrofluorination. When the fluoropolymer is capable of dehydrofluorination, the cure composition will typically comprise a dehydrofluorinating agent. Examples of materials
 30 useful as dehydrofluorinating agents include organo-oniums, such as those discussed in the

below. Another class of useful dehydrofluorinating agents are bases, such as 1,8 diaza[5.4.0]bicyclo undec-7-ene, (DBU) and 1,5-diazabicyclo[4.3.0]-5-nonene, (DBN). Preferred dehydrofluorinating agents include tributyl(2-methoxy)-propylphosponium chloride, triphenyl benzyl phosphonium chloride, complexes of tributyl(2-methoxy)-phosphonium chloride with bisphenol AF, and DBU. Combinations of dehydrofluorinating agents may be employed if desired.

If the fluoropolymer lacks cure components, the dehydrofluorinating agent must be employed so as to cure the fluoropolymer. An effective amount of dehydrofluorinating agent to cure the fluoropolymer is dependent upon the fluoropolymer employed and the reactivity of the other additives used. Within these parameters, an effective amount of dehydrofluorinating agent is generally from 0.01 to 20 parts per one hundred parts of the fluoropolymer. Preferred addition levels are from 0.1 to 5 parts per hundred.

Generally, a cure composition including a dehydrofluorinating agent will also comprise a polyhydroxy compound. In addition to the polyhydroxy compound, the cure composition generally also comprises one or more organo-onium accelerators. The organo-onium compounds useful in the present invention typically contain at least one heteroatom, i.e., a non-carbon atom such as N, P, S, O, bonded to organic or inorganic moieties and include for example ammonium salts, phosphonium salts and iminium salts. One class of quaternary organo-onium compounds useful in the present invention broadly comprises relatively positive and relatively negative ions wherein a phosphorus, arsenic, antimony or nitrogen generally comprises the central atom of the positive ion, and the negative ion may be an organic or inorganic anion (e.g., halide, sulfate, acetate, phosphate, phosphonate, hydroxide, alkoxide, phenoxide, bisphenoxide, etc.).

Many of the organo-onium compounds useful in this invention are described and known in the art. See, for example, U.S. Pat. Nos. 4,233,421 (Worm), 4,912,171 (Grootaert et al.), 5,086,123 (Guenther et al.), and 5,262,490 (Kolb et al.), US 5,929,169. Representative examples include the following individually listed compounds and mixtures thereof:

- triphenylbenzyl phosphonium chloride
- tributylallyl phosphonium chloride
- tributylbenzyl ammonium chloride
- tetrabutyl ammonium bromide

triaryl sulfonium chloride

8-benzyl-1,8-diazabicyclo [5,4,0]-7-undecenium chloride

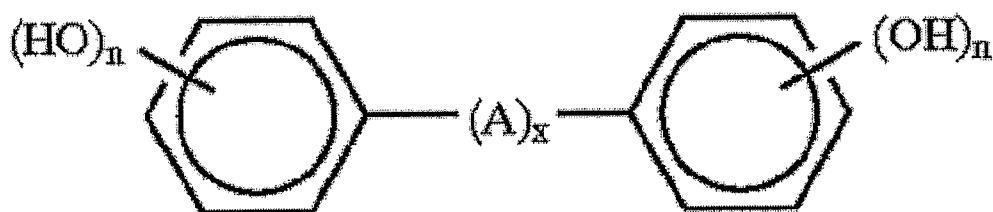
benzyl tris(dimethylamino) phosphonium chloride

benzyl(diethylamino)diphenylphosphonium chloride

5

Another class of useful organo-onium compounds include those having one or more pendent fluorinated alkyl groups. Generally, the most useful fluorinated onium compounds are disclosed by Coggio et al. in U.S. Pat. No. 5,591,804.

- 10 The polyhydroxy compound may be used in its free or non-salt form or as the anionic portion of a chosen organo-onium accelerator. The crosslinking agent may be any of those polyhydroxy compounds known in the art to function as a crosslinking agent or co-curative for fluoroelastomers, such as those polyhydroxy compounds disclosed in U.S. Pat. Nos. 3,876,654 (Pattison), and 4,233,421 (Worm). Representative aromatic polyhydroxy compounds include
- 15 any one of the following: di-, tri-, and tetrahydroxybenzenes, naphthalenes, and anthracenes, and bisphenols of the following formula:



- wherein A is a difunctional aliphatic, cycloaliphatic, or aromatic radical of 1 to 13 carbon atoms, or a thio, oxy, carbonyl, sulfonyl, or sulfonyl radical, A is optionally substituted with at
- 20 least one chlorine or fluorine atom, x is 0 or 1, n is 1 or 2, and any aromatic ring of the polyhydroxy compound is optionally substituted with at least one atom of chlorine, fluorine, bromine, or with a carboxyl or an acyl radical (e.g., --COR where R is H or a C1 to C8 alkyl, aryl, or cycloalkyl group) or alkyl radical with, for example, 1 to 8 carbon atoms. It will be understood from the above bisphenol formula that the --OH groups can be attached in any
- 25 position (other than number one) in either ring. Blends of two or more of these compounds are also used.

One of the most useful and commonly employed aromatic polyphenols of the above formula is 4,4'-hexafluoroisopropylidene bisphenol, known more commonly as bisphenol AF. The compounds 4,4'-dihydroxydiphenyl sulfone (also known as Bisphenol S) and 4,4'-isopropylidene bisphenol (also known as bisphenol A) are also widely used in practice.

5

The cure composition based on a dehydrofluorinating agent may further include an acid acceptor. Acid acceptors can be inorganic or blends of inorganic and organic. Examples of inorganic acceptors include magnesium oxide, lead oxide, calcium oxide, calcium hydroxide, dibasic lead phosphite, zinc oxide, barium carbonate, strontium hydroxide, calcium carbonate,
10 etc. Organic acceptors include epoxies, sodium stearate, and magnesium oxalate. The preferred acid acceptors are magnesium oxide and calcium hydroxide. The acid acceptors can be used singly or in combination, and preferably are used in amounts ranging from about 2 to 25 parts per 100 parts by weight of the fluoropolymer.

15 When the fluoropolymer is capable of dehydrofluorination and further includes one or more cure site components, it will be clear that the cure composition may include both a combination of cure components to cause dehydrofluorination and curing of the cure site components.

20 The curable fluoroelastomer composition may contain further additives, such as carbon black, stabilizers, plasticizers, lubricants, fillers, and processing aids can be incorporated into the compositions, provided they have adequate stability for the intended service conditions. The compositions may be prepared by mixing the fluoropolymer, a cure composition and other additives in conventional rubber processing equipment. Such equipment includes rubber
25 mills, internal mixers, such as Banbury mixers, and mixing extruders.

The curable fluoroelastomer compositions can be used to provide a fluoroelastomer upon curing. In one particular embodiment, the curable fluoroelastomer composition is extruded and cured to obtain a fluoroelastomer article, for example a tube. In another embodiment, the
30 curable fluoroelastomer composition may be used in injection molding and cured to provide an injection molded article such as a gasket or O-ring.

The invention will now be further illustrated by the following examples without however the intention to limit the invention thereto.

EXAMPLES

Measurement methods

- 5 Solution viscosities of diluted polymer solutions were typically determined on a 0.16% polymer solution in methylethylketone (MEK) at 35°C in accordance to DIN 53726. A *Connon-Fenske-Routine-Viskosimeter* (Fa. Schott, Mainz/Germany) fulfilling ISO/DIS 3105 and ASTM D 2515 was used for the measurements, the *Hagenbach* correcture was applied. The so-obtained reduced viscosities $\eta_{\text{red.}}$ were converted into the intrinsic viscosity $[\eta]$ using
- 10 the *Huggins* equation ($\eta_{\text{red.}} = [\eta] + k_H \times [\eta]^2 \times c$) and a *Huggins* constant of $k_H = 0.34$. The intrinsic viscosity $[\eta]$ and the reduced viscosity $\eta_{\text{red.}}$ are reported in physical units of ml/g.

- A strain controlled ARES rheometer of *Rheometry Scientific* was used to evaluate the zero shear viscosity η_0 at 265°C. The dynamic mechanical data of the fluoropolymer were
- 15 recorded in frequency sweep experiments using a 25 mm parallel plate geometry in nitrogen atmosphere. The strains were typically ranging from 1 to 20%. Zero shear viscosities η_0 were extrapolated using the 4 parameter *Carreau* fit function of the orchestrator software, the correlation coefficient was usually $r^2 \geq 0.998$.

- 20 A melt flow index (MFI) instrument was used as constant stress rheometer to assess the extrusion properties of the polymers cited here. The melt flow indices (MFI), given in units of g/10', were obtained according to DIN 53735, ISO 12086 or ASTM D-1238 at a temperature of 265°C and with a standardized extrusion die of 2.1 mm diameter and a length of 8.0 mm. A variety of standardized support weights were applied (1.2, 2.16, 3.8, 5.0, 10.0 & 21.6 kg).
- 25 The support weight m_{MFI} can be converted into the apparent shear stress using the following empirical relation: $\log[\tau_{\text{app.}}/\text{Pa}] = 1.03 \times \log[m_{\text{MFI}}/\text{kg}] + 3.88$. Using a polymer density at 265°C of 1,50 g/cm³, the apparent shear rate $\dot{\gamma}_{\text{app.}}$, given in physical units of 1/s, were calculated from the MFI by: $\dot{\gamma}_{\text{app.}} = 1.23 \times \text{MFI}$. The extruded MFI strands were visually inspected in terms of melt fracture. The critical shear rates $\dot{\gamma}_{\text{crit.}}$ (the shear rate that marks the
- 30 onset of melt fracture) cited here refer to an interpolated critical wall stress of $\tau_{\text{crit.}} = 1.31\text{e5 Pa}$.

The latex particle size determination was conducted by means of dynamic light scattering with a *Malvern Zetazizer 1000 HSA* in accordance to ISO/DIS 13321. Prior to the measurements, the polymer latexes as obtained from the polymerisations were diluted with 0.001 mol/L KCl-solution, the measurement temperature was 20°C in all cases.

5

The molar compositions of TFE/HFP/VDF terpolymers cited here were determined by means of transmission infrared spectroscopy according to the following procedure: 150 ± 10 mg purified raw gum were dissolved into 2 ± 0.2 ml acetone. This polymer solution was homogeneously placed onto a KBr press sintered plate (from *Spectra-Tech.*) using a *Chemat Technology KW-4A* spin coater (10s at 750 rpm and 20 s at 1250 rpm). The so-obtained polymer films were dried under a *Mettler-Toledo LP 16* halogen lamp for 5 min at 60°C. The polymer infrared spectra in a spectral range of 4000 to 400 1/cm were recorded in 164 scans of a *Nicolet DX 510* FT-IR spectrometer operating in extinction mode under nitrogen atmosphere. The thickness of the polymer film is adjusted to give an extinction in between 0.5 and 0.7 at 1194 1/cm. The compositional analysis of the raw data spectra was conducted by means of partial least square (PLS) method of the *Grams/32, Vers. 5.1a* software. This PLS method was calibrated using 41 individual TFE/HFP/VDF terpolymer standard samples of different compositions ranging from 68.3 to 72.6% fluorine content (quantified by $^1\text{H}/^{19}\text{F}$ cross integration NMR technique).

20

Cure Rheology Test were run on uncured, compounded admixtures using an Alpha Technology Moving Die Rheometer (MDR) Model 2000 in accordance with ASTM D 5289-95 at 177°C, no preheat, 12 minutes elapsed time (unless otherwise specified) and a 0.5 arc. Minimum torque (M_L), Maximum torque (M_H), i.e., highest torque attained during specified period of time when no plateau or maximum was obtained and difference in Torque ($M_H - M_L$) were reported. Also reported were: t_{s2} (time for torque to increase 2 units above M_L), $t'50$ (time for torque to reach $M_L + 0,5[M_H - M_L]$, and $t'90$ (time for torque to reach $M_L + 0,9[M_H - M_L]$).

Press-cured samples (150 x 150 x 2.0 mm sheets, unless otherwise noted) were prepared for physical property determination by pressing at about 22 MPa for at 177°C for 10 minutes. Post cure samples were prepared by placing a press-cured sample in a circulating air oven. The oven was maintained at 232°C and the samples treated for 16 hours.

Tensile Strength at Break, Elongation at Break, and Modulus at 100% Elongation were determined using DIN 53504 on samples cut from 2.0 mm sheet with DIN S2 die. Units are reported in Mega Pascals (MPa). Hardness was determined using ASTM D 2240-02 method A with a Type A-2 Shore Durometer.

Example 1

A polymerization kettle with a total volume of 48.5 l equipped with an impeller agitator system was charged with 29.0 l deionized water. The oxygen free kettle was then heated up to 70°C and the agitation system was set to 240 rpm. The kettle was charged with 4 g of dimethylether, 1217 g hexafluoropropylene (HFP) to a pressure of 10.2 bar absolute, with 180 g vinylidene fluoride (VDF) to 13.5 bar absolute and with 168 g tetrafluoroethylene (TFE) to 15.5 bar absolute reaction pressure. The polymerization was initiated by the addition of 40 g ammonium peroxodisulfate (APS, dissolved into 120 ml water). As the reaction starts, the reaction temperature of 70°C was maintained and the reaction pressure of 15.5 bar absolute was maintained by the feeding TFE, VDF and HFP, into the gas phase with a feeding ratio HFP (kg)/VDF (kg) of 1.029 and a feeding ratio TFE (kg)/VDF (kg) of 0.726. When a total feed of 2700 g VDF was reached in 105 min, the feed of the monomers was interrupted by closing the monomer valves. Within 10 minutes, the monomer gas phase was reacted down to a kettle pressure of 9.5 bar. Then the reactor was vented and flushed with N₂ in three cycles.

The so-obtained 36.5 kg polymer dispersion having a solid content of 20.7% and a latex particles having 485 nm in diameter according to dynamic light scattering was removed at the bottom of the reactor.

5.0 l of this polymer dispersion was freeze coagulated over night in a refrigerator. After thawing the material, the so-obtained sponge-like raw polymer was washed five times with demineralised water, the polymer was squeezed out and dried for 12 h in an oven at 130°C. The thus obtained polymer has a composition of 22.8 mole % TFE, 22.9 mole % HFP and 54.3 mole % VDF and is readily soluble in methylethyl ketone (MEK) and tetrahydrofuran (THF), it showed the physical characteristics listed below:

- | | |
|---|---------------|
| - MFI(265/5): | 12.2 g/10 min |
| - zero shear viscosity η_0 at 265°C: | 3.8e3 Pa·s |

- reduced viscosity (MEK@35°C):	76 ml/g
- intrinsic viscosity (MEK@35°C):	73 ml/g
- LCBI:	0.01
- critical shear rate:	93 s ⁻¹

5

From these and similarly prepared samples but with different amount of dimethylether, a correlation was established between the critical shear rate ($\dot{\gamma}_{crit.}$) and zero shear rate viscosity η_0 for the TFE₂₃/HFP₂₃/VDF₅₄ terpolymers. This correlation is as follows:

$$\log[\dot{\gamma}_{crit.}/s^{-1}] = 5.55 - \log[\eta_0/Pa \cdot s] \quad \text{eq. 1}$$

- 10 Based on the fact that the investigated terpolymers have an essentially linear chain topology (note that the LCBI is very close to zero), the zero shear viscosity η_0 can be related to the intrinsic viscosity as follows:

$$\eta_0 = 5.5e-8 \times [\eta]^{5.8} \quad \text{eq. 2}$$

15 **Synthesis of LCB fluoropolymers**

- Long chain branched fluoropolymers (TFE₂₃/HFP₂₃/VDF₂₃ terpolymers) were made essentially according to the procedure above. The dimethylether batch charge was varied in each case. Further, small amounts of BDFE were additionally fed into the kettle during the course of polymerization. The dimethylether batch charges as well as the total BDFE amounts
20 utilized are summarized in the following table together with the physical data of the test results.

Table 1:

Comp.Example		LCB-FE 1		LCB-FE 2		LCB-FE 3		LCB-FE 4		LCB-FE 5		LCB-FE 6	
Me ₂ O [g]	4.0	3.0		4.5		5.5		3.0		4.0		5.0	
BDFE [g]	0	10		10		10		25		25		25	
BDFE feed [%]	0	0.13		0.13		0.13		0.34		0.34		0.34	
IR-composition TFE/HFP/VDF	22.8/22.9/54.3	23.8/22.3/53.9		22.6/22.0/55.4		24.1/21.8/54.1		22.4/22.1/55.5		24.6/21.3/54.1		22.0/22.3/55.7	
η_{red} [ml/g]	76	77		71		60		83		67,5		64.5	
$[\eta]$ [ml/g]	73	74		68,5		58		79,5		65		62	
$\eta_0(265^\circ\text{C})[\text{Pa}\cdot\text{s}]$	3.8e3	1.8e5		4.0e4		6.3e3		2.5e6		4.5e5		4.0e4	
LCBI [I]	0.01	0.94		0.62		0.39		1.85		1.59		0.79	
$\gamma^*_{crit.} / \text{Pa}$	93	26		57		155		14		29		56	
MFI load	$\tau_{app.} / \text{Pa}$	MFI [g/10']	$\dot{\gamma}^*_{app.}$ [1/s]	MFI [g/10']	$\dot{\gamma}^*_{app.}$ [1/s]	MFI [g/10']	$\dot{\gamma}^*_{app.}$ [1/s]	MFI [g/10']	$\dot{\gamma}^*_{app.}$ [1/s]	MFI [g/10']	$\dot{\gamma}^*_{app.}$ [1/s]	MFI [g/10']	$\dot{\gamma}^*_{app.}$ [1/s]
1.2 kg	9.15e3	2.05	2.5	0.25	0.31	0.67	0.82	2.24	2.8	0.08	0.10	0.24	0.30
2.16 kg	1.68e4	4.3	5.3	0.58	0.71	1.68	2.1	5.58	6.9	0.29	0.36	0.69	0.85
3.8 kg	3.00e4	8.0	9.8	1.55	1.91	4.1	5.0	11.7	14.4	0.66	0.81	1.70	2.1
5.0 kg	3.98e4	12.2	15.0	2.70	3.3	10.1	12.4	21.5	26.4	1.4	1.72	3.53	4.3
10.0 kg	8.13e4	33	40.6	8.65	10.6	20.2	24.8	54	66.4	5.8	7.1	8.9	11.0
21.6 kg	1.80e5	150*)	185*)	45*)	55*)	87*)	107*)	240*)	295*)	37*)	45.5*)	52*)	64*)

*) melt fracture observed at the extruded MFI strand

On the basis of equation 1, one can calculate the critical shear rate $\dot{\gamma}_{crit.}(lin.)$ for the corresponding linear fluoropolymer of the same molecular weight. With the observed values $\dot{\gamma}_{crit.}(br.)$ recorded for the branched fluoropolymer, the ratio $\dot{\gamma}_{crit.}(br.) / \dot{\gamma}_{crit.}(lin.)$ can be calculated quantifying the factor of improvement of the processing properties. These values are summarized in Table 2.

Table 2:

Example	$\dot{\gamma}_{crit.}(br.) / \dot{\gamma}_{crit.}(lin.)$	LCBI
LCB-FE 1	13.2	0.94
LCB-FE 2	6.4	0.62
LCB-FE 3	2.8	0.39
LCB-FE 4	102.6	1.85
LCB-FE 5	36.8	1.59
LCB-FE 6	6.3	0.79

It is observed that the fluoropolymers having a LCBI of 1 show a tenfold higher critical shear rate compared to a prior art polymer with the same zero shear viscosity. The critical shear rate is even increased by factor of 100 for a branched polymer with LCBI of 2. For the polymers summarized in Table 2, this observation can be quantified with the following empirical equation:

$$\log[\dot{\gamma}_{crit.}(br.) / \dot{\gamma}_{crit.}(lin.)] \approx \text{LCBI} \quad \text{equation 3}$$

$$r^2 = 0.99$$

This improved processing behavior is beneficial in particular for tube extrusion and injection molding applications.

Example 2

As described in the following, the comparative polymer of Example 1 and LCB-FE 3 polymer were press-cured using a Bisphenol cure package and various physical properties were measured. In each case, 100 parts of the polymer were mixed on a two roll mill with the following ingredients:

- 1.285 mmol of triphenyl benzyl phosphonium chloride
- 4.85 mmol Bisphenol-AF
- 3 g magnesium oxide (Elastomag 170 from *Morton International*)
- 6 g calcium hydroxide
- 5 • 30 g carbon black (MT-990).

These two cure compounds were tested and compared to each other for curing rheology and mechanical properties. The test results are reported in Table 3.

Table 3

	Example 1	LCB-FE 3
Curing properties (MDR, 0.5° 12'@177°C)		
Minimum torque, ML [in/lbs]	1.2	1.5
Maximum torque, MH [in/lbs]	13.8	11.3
MH - ML [in/lbs]	12.7	9.8
Ts2 [minutes]	1.64	1.95
t'50 [minutes]	2.48	2.63
t'90 [minutes]	5.14	5.04
Physical properties of press cured sheet		
Hardness (Durometer, shore A)	73	73
Tensile strength [MPa]	14.4	11.2
Elongation [%]	319	391
100% Modulus [MPa]	3.2	2.8

10

Example 3

A long chain branched TFE₂₃/HFP₂₃/VDF₂₃ terpolymer was prepared essentially according to the procedure of LCB-FE 3. The dimethylether batch charge was 5.0 g, the amount of
 15 BDFE utilized was 10 g. Further, 66 g (0.4 mole % of monomer feed) of 4-bromo-3,3,4,4,-tetrafluorobutene-1 (BTFB) cure site monomer was continuously fed during the course of polymerization together with 10 g of BDFE. The polymerization took 275 min. The so-

obtained dispersion having a solid content of 20.2% showed latex particles with 448 nm in average diameter according to dynamic light scattering. The physical data are listed below:

	- MFI(265/1.2):	11.2 g/10 min
5	- MFI(265/2.16):	26.0 g/10 min
	- MFI(265/3.8):	54 g/10 min
	- MFI(265/5):	106 g/10 min
	- MFI(265/10):	230 g/10 min
	- MFI(265/21.6):	841 g/10 min (melt fracture observed)
10	- zero shear viscosity η_0 at 265°C:	6.8e2 Pa·s
	- reduced viscosity (MEK@35°C):	40 ml/g
	- intrinsic viscosity (MEK@35°C):	39 ml/g
	- LCBI:	0.41
	- critical shear rate:	640 s ⁻¹

15

The critical shear rate of this polymer example is improved by 25% compared to an equivalent linear polymer.

20

CLAIMS

1. A composition comprising an amorphous fluoropolymer wherein the amorphous fluoropolymer (i) has one or more cure site components, said cure site components being
 5 contained in said amorphous fluoropolymer in an amount between 0.1 and 0.5 mole % based on the total amount of repeating units in the amorphous fluoropolymer or (ii) is capable of being dehydrofluorinated, wherein said amorphous fluoropolymer is derivable from a polymerization of (a) one or more gaseous fluorinated monomers and (b) not more than 0.5% by weight based on the total weight of monomers of one or more olefins having a
 10 bromine or iodine atom bonded to a carbon of the double bond of the olefin or (iii) has some combination of (i) and (ii).
2. An amorphous fluoropolymer according to claim 1 wherein at least part of said cure sites are comprised in end groups of said amorphous fluoropolymer.
 15
3. An amorphous fluoropolymer according to claim 1 or 2 wherein said cure sites comprise a halogen capable of participating in a peroxide cure reaction.
4. An amorphous fluoropolymer according to claim 3 wherein said cure sites derive from a
 20 cure site monomer according to the formula:

$$\text{CX}_2=\text{CX}-\text{R}_f-\text{Z}$$
 wherein each X independently represents H, F or Cl, R_f represents a perfluorinated aliphatic group that may contain one or more oxygen atoms and Z represents Br or I.
- 25 5. An amorphous fluoropolymer according to claim 1 wherein said cure sites comprise a nitrile group.
6. An amorphous fluoropolymer according to claim 5 wherein said cure site derive from a monomer having the formula:
 30
$$\text{CF}_2=\text{CF}-\text{R}^a_f-\text{CN}$$
 wherein R^a_f represents a perfluorinated aliphatic group that may contain one or more oxygen atom.

7. An amorphous fluoropolymer according to claim 1 wherein at least one of said gaseous fluorinated monomers is vinylidene fluoride.
- 5 8. An amorphous fluoropolymer according to claim 1 wherein said amorphous fluoropolymer is a copolymer of tetrafluoroethylene, hexafluoropropylene and vinylidene fluoride.
9. A curable composition for making a fluoroelastomer, said composition comprising an
10 amorphous fluoropolymer as defined in claim 1 and a cure composition comprising one or more components for curing said amorphous fluoropolymer.
10. A curable composition according to claim 9 wherein said amorphous fluoropolymer comprises cure sites and wherein said cure composition comprises an organic peroxide.
15
11. A curable composition according to claim 9 wherein said amorphous fluoropolymer is capable of dehydrofluorination and wherein said cure composition comprises a dehydrofluorinating agent and a polyhydroxy compound.
- 20 12. Method of making an elastomer article comprising injection molding or extruding a curable composition as defined in claim 9 and curing said curable composition.
13. Method of producing an amorphous fluoropolymer as defined in claim 1, the method comprising polymerizing (a) one or more gaseous fluorinated monomers and (b) not more
25 than 0.5% by weight based on the total weight of monomers of one or more olefins having a bromine or iodine atom bonded to a carbon of the double bond of the olefin and providing capability for the fluoropolymer to be cured by (i) polymerizing the one or more gaseous fluorinated monomers in the presence of one or more components comprising a cure site, the total amount of said components being sufficient for introducing between 0.1 and 0.5 mole
30 % of cure site components in the amorphous fluoropolymer or (ii) selecting at least one partially fluorinated gaseous monomer as said one or more gaseous fluorinated monomers or copolymerizing said gaseous fluorinated monomers with one or more non-fluorinated

comonomers or partially fluorinated non-gaseous monomers so as to provide an amorphous fluoropolymer capable of being dehydrofluorinated.