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(54) Titre : COMPOSITIONS THERMODURCISSABLES RENFERMANT DES POLYMERES EPOXY FONCTIONNELS
OBTENUS PAR POLYMERISATION RADICALE A TRANSFERT D'ATOMES
(54) Title: THERMOSETTING COMPOSITIONS CONTAINING EPOXY FUNCTIONAL POLYMERS PREPARED BY
ATOM TRANSFER RADICAL POLYMERIZATION

(57) **Abrégé/Abstract:**

A thermosetting composition comprising a co-reactable solid, particulate mixture of (a) epoxy functional polymer, and (b) co-reactant having functional groups reactive with the epoxy groups of (a), e.g., dodecanedioic acid, is described. The epoxy functional polymer is prepared by atom transfer radical polymerization and has well defined polymer chain architecture and polydispersity index of less than 2.5. The thermosetting compositions of the present invention have utility as powder coatings compositions.



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(54) Title: THERMOSETTING COMPOSITIONS CONTAINING EPOXY FUNCTIONAL POLYMERS PREPARED BY ATOM TRANSFER RADICAL POLYMERIZATION (57) Abstract A thermosetting composition comprising a co-reactable solid, particulate mixture of (a) epoxy functional polymer, and (b) co-reactant having functional groups reactive with the epoxy groups of (a), e.g., dodecanedioic acid, is described. The epoxy functional polymer is prepared by atom transfer radical polymerization and has well defined polymer chain architecture and polydispersity index of less than 2.5. The thermosetting compositions of the present invention have utility as powder coatings compositions.		

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**THERMOSETTING COMPOSITIONS CONTAINING EPOXY FUNCTIONAL
POLYMERS PREPARED BY ATOM TRANSFER RADICAL POLYMERIZATION**

10 **FIELD OF THE INVENTION**

The present invention relates to thermosetting compositions of one or more epoxy functional polymers and one or more coreactants having functional groups that are reactive with epoxides. The epoxy functional polymer is prepared by
15 atom transfer radical polymerization, and has well defined polymer chain structure, molecular weight and molecular weight distribution. The present invention also relates to methods of coating a substrate, substrates coated by such methods, and composite coating compositions.

20

BACKGROUND OF THE INVENTION

Reducing the environmental impact of coatings compositions, in particular that associated with emissions into the air of volatile organics during their use, has been
25 an area of ongoing investigation and development in recent years. Accordingly, interest in powder coatings has been increasing due, in part, to their inherently low volatile organic content (VOC), which significantly reduces air emissions during the application process. While both
30 thermoplastic and thermoset powder coatings compositions are commercially available, thermoset powder coatings are typically more desirable because of their superior physical properties, e.g., hardness and solvent resistance.

Low VOC coatings are particularly desirable in the
35 automotive original equipment manufacture (OEM) market, due to the relatively large volume of coatings that are used. However, in addition to the requirement of low VOC levels,

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automotive manufactures have very strict performance requirements of the coatings that are used. For example, automotive OEM clear top coats are typically required to have a combination of good exterior durability, acid etch and water spot resistance, and excellent gloss and appearance. While liquid top coats, in particular epoxy-acid cured liquid coatings, can provide such properties, they have the undesirable draw back of higher VOC levels relative to powder coatings, which have essentially zero VOC levels.

10 Epoxy based powder coatings, such as epoxy-acid powder coatings, are known and have been developed for use as automotive OEM clear top coats. However, their use has been limited due to deficiencies in, for example, flow, appearance and storage stability. Epoxy based powder coating compositions typically comprise a co-reactant, e.g., a crosslinking agent, having functional groups that are reactive with epoxides, e.g., dodecanedioic acid, and an epoxy functional polymer, e.g., an acrylic copolymer prepared in part from glycidyl methacrylate. The epoxy functional polymers used in such epoxy based powder coatings compositions are typically prepared by standard, i.e., non-living, radical polymerization methods, which provide little control over molecular weight, molecular weight distribution and polymer chain structure.

25 The physical properties, e.g., glass transition temperature (T_g) and melt viscosity, of a given polymer can be directly related to its molecular weight. Higher molecular weights are typically associated with, for example, higher T_g values and melt viscosities. The physical properties of a polymer having a broad molecular weight distribution, e.g., having a polydispersity index (PDI) in excess of 2.0 or 2.5, can be characterized as an average of the individual physical properties of and indeterminate interactions between the various polymeric species that comprise it. As such, the physical properties of polymers having broad molecular weight distributions can be variable and hard to control.

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The polymer chain structure, or architecture, of a copolymer can be described as the sequence of monomer residues along the polymer back bone or chain. For example, an epoxy functional copolymer prepared by standard radical
5 polymerization techniques will contain a mixture of polymer molecules having varying individual epoxy equivalent weights. Some of these polymer molecules can actually be free of epoxy functionality. In a thermosetting composition, the formation of a three dimensional crosslinked network is dependent upon
10 the functional equivalent weight as well as the architecture of the individual polymer molecules that comprise it. Polymer molecules having little or no reactive functionality (or having functional groups that are unlikely to participate in crosslinking reactions due to their location along the polymer
15 chain) will contribute little or nothing to the formation of the three dimensional crosslink network, resulting in less than optimum physical properties of the finally formed polymerizate, e.g., a cured or thermoset coating.

The continued development of new and improved epoxy based
20 powder coatings compositions having essentially zero VOC levels and a combination of favorable performance properties is desirable. In particular, it would be desirable to develop epoxy based powder coatings compositions that comprise epoxy functional polymers having well defined molecular weights and
25 polymer chain structure, and narrow molecular weight distributions, e.g., PDI values less than 2.5. Controlling the epoxy polymer architecture and polydispersity is desirable in that it enables one to achieve higher Tg's and lower melt viscosities than comparable epoxy polymers prepared by
30 conventional processes, resulting in thermosetting particulate compositions which are resistant to caking and have improved physical properties.

International patent publication WO 97/18247 and United States Patent No.'s 5,763,548 and 5,789,487 describe a radical
35 polymerization process referred to as atom transfer radical polymerization (ATRP). The ATRP process is described as being

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a living radical polymerization that results in the formation of (co)polymers having predictable molecular weight and molecular weight distribution. The ATRP process is also described as providing highly uniform products having controlled structure (i.e., controllable topology, composition, etc.). The '548 and '487 patents and WO 97/18247 patent publication also describe (co)polymers prepared by ATRP, which are useful in a wide variety of applications, for example, with paints and coatings.

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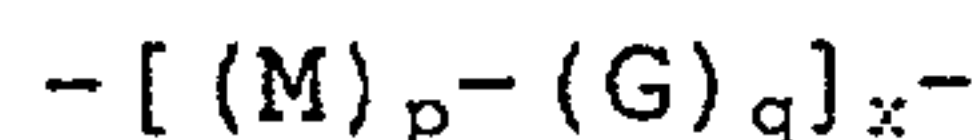
SUMMARY OF THE INVENTION

In accordance with the present invention there is provided, a thermosetting composition comprising a co-reactable solid, particulate mixture of:

15 (a) epoxy functional polymer prepared by atom transfer radical polymerization initiated in the presence of an initiator having at least one radically transferable group, and in which said epoxy functional polymer contains at least one of the following polymer chain structures I and II:

20

I



and

II

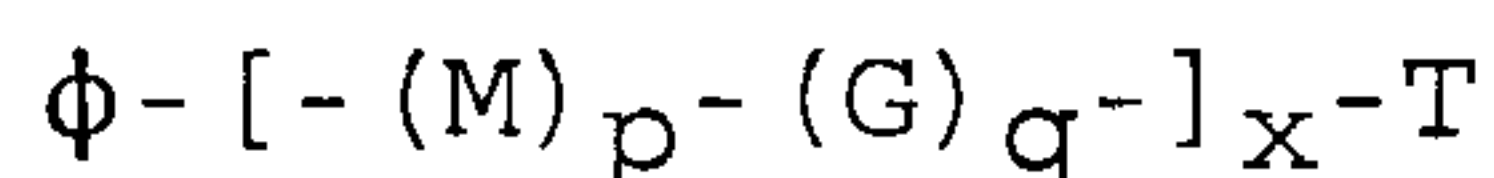


25 wherein M is a residue, that is free of oxirane functionality, of at least one ethylenically unsaturated radically polymerizable monomer; G is a residue, that has oxirane functionality, of at least one ethylenically unsaturated radically polymerizable monomer; p and q represent average numbers of residues occurring in a block of residues in each polymer chain structure; and p, q and x are each individually selected for each structure such that said epoxy functional polymer has a number average molecular weight of at least 250; and

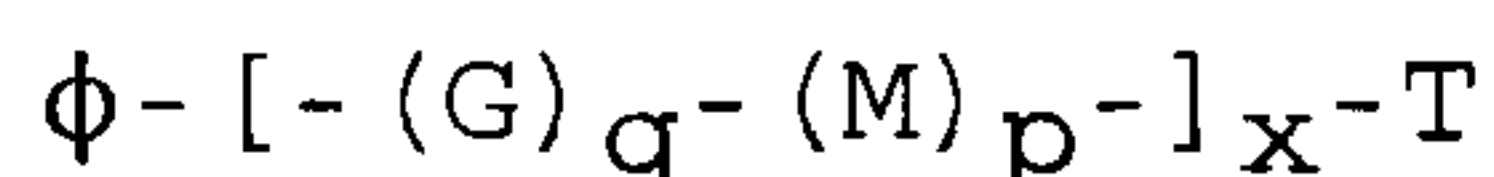
35 (b) co-reactant having functional groups reactive with the epoxy groups of (a).

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In accordance with the present invention there is further provided a thermosetting composition comprising a co-reactable solid, particulate mixture of: (a) a block epoxy functional copolymer prepared by atom transfer radical polymerization initiated in the presence of an initiator having at least one radically transferable group, and in which said epoxy functional polymer contains at least one of the following polymer chain structures:



and



wherein M is a residue, that is free of oxirane functionality, of at least one ethylenically unsaturated radically polymerizable monomer; G is a residue, that has oxirane functionality, of at least one ethylenically unsaturated radically polymerizable monomer; ϕ is or is derived from a residue from the initiator, free from the radically transferable group, selected from the group consisting of linear or branched aliphatic compounds, cycloaliphatic compounds, heterocyclic compounds, sulfonyl compounds, sulfenyl compounds, esters of carboxylic acids, polymeric compounds and mixtures thereof; T is or is derived from the radically transferable group and is selected from the group consisting of halide and a dehalogenation reaction product of a limited radically polymerizable ethylenically unsaturated compound; p and q represent average numbers of residues occurring in a block of residues in each polymer chain structure; p, q and x are each individually selected for each structure such that said epoxy functional polymer has a number average molecular weight of at least 250; a polydispersity of less than 2.5; p is an integer of from 1

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to 100; q is an integer of from 1 to 15; and x is an integer of from 1 to 10; and wherein the epoxy functional polymer has an epoxy equivalent weight of from 200 to 1,000 grams/equivalent; and (b) co-reactant having functional groups reactive with the epoxy groups of (a).

In accordance with the present invention, there is also provided a method of coating a substrate with the above described thermosetting composition and a substrate so coated.

There is further provided, in accordance with the present invention, a multi-component composite coating composition comprising a base coat deposited from a pigmented film-forming composition, and a transparent top coat applied over the base coat. The transparent top coat comprises the above described thermosetting composition.

Other than in the operating examples, or where otherwise indicated, all numbers expressing quantities of ingredients, reaction conditions, and so forth used in the specification and claims are to be understood as modified in all instances by the term "about".

As used therein, the term "polymer" is meant to refer to both homopolymers, i.e., polymers made from a single monomer species, and copolymers, i.e., polymers made from two or more monomer species.

DETAILED DESCRIPTION OF THE INVENTION

Thermosetting compositions in accordance with the present invention, comprise one or more epoxy functional polymers. As used herein and in the claims, by "epoxy functional polymer" is meant a polymer having two or more epoxy groups in terminal and/or pendent positions that are capable of reacting and forming covalent bonds with compounds containing functional groups reactive with

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epoxides, e.g., hydroxyl, thiol, amine and carboxylic acid groups.

The epoxy functional polymer of the present invention is prepared by atom transfer radical polymerization (ATRP). The ATRP method is described as a "living polymerization," i.e., a chain-growth polymerization that propagates with essentially no chain transfer and essentially no chain termination. The molecular weight of a polymer prepared by ATRP can be controlled by the stoichiometry of the reactants, i.e., the initial concentration of monomer(s) and initiator(s). In

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addition, ATRP also provides polymers having characteristics including, for example, narrow molecular weight distributions, e.g., PDI values less than 2.5, and well defined polymer chain structure, e.g., block copolymers and alternating copolymers.

5 The ATRP process can be described generally as comprising: polymerizing one or more radically polymerizable monomers in the presence of an initiation system; forming a polymer; and isolating the formed polymer. The initiation system comprises: an initiator having a radically transferable
10 atom or group; a transition metal compound, i.e., a catalyst, which participates in a reversible redox cycle with the initiator; and a ligand, which coordinates with the transition metal compound. The ATRP process is described in further detail in international patent publication WO 97/18247 and
15 United States Patent No.'s 5,763,548 and 5,789,487.

 In preparing epoxy functional polymers of the present invention, the initiator may be selected from the group consisting of linear or branched aliphatic compounds, cycloaliphatic compounds, aromatic compounds, polycyclic
20 aromatic compounds, heterocyclic compounds, sulfonyl compounds, sulfenyl compounds, esters of carboxylic acids, polymeric compounds and mixtures thereof, each having at least one radically transferable group, which is typically a halo group. The initiator may also be substituted with functional
25 groups, e.g., oxyranyl groups, such as glycidyl groups. Additional useful initiators and the various radically transferable groups that may be associated with them are described on pages 42 through 45 of international patent publication WO 97/18247.

30 Polymeric compounds (including oligomeric compounds) having radically transferable groups may be used as initiators, and are herein referred to as "macroinitiators." Examples of macroinitiators include, but are not limited to, polystyrene prepared by cationic polymerization and having a
35 terminal halide, e.g., chloride, and a polymer of 2-(2-bromopropionyloxy) ethyl acrylate and one or more alkyl

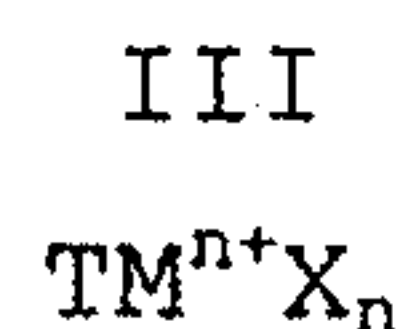
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(meth)acrylates, e.g., butyl acrylate, prepared by conventional non-living radical polymerization.

Macroinitiators can be used in the ATRP process to prepare graft polymers, such as grafted block copolymers and comb
5 copolymers. A further discussion of macroinitiators is found on pages 31 through 38 of international patent publication WO 98/01480.

Preferably, the initiator may be selected from the group consisting of halomethane, methylenedihalide, haloform, carbon
10 tetrahalide, 1-halo-2,3-epoxypropane, methanesulfonyl halide, p-toluenesulfonyl halide, methanesulfonyl halide, p-toluenesulfonyl halide, 1-phenylethyl halide, C₁-C₆-alkyl ester of 2-halo-C₁-C₆-carboxylic acid, p-halomethylstyrene, mono-hexakis(α -halo-C₁-C₆-alkyl)benzene, diethyl-2-halo-2-methyl
15 malonate, ethyl 2-bromoisobutyrate and mixtures thereof. A particularly preferred initiator is diethyl-2-bromo-2-methyl malonate.

Catalysts that may be used in preparing epoxy functional polymers of the present invention, include any transition
20 metal compound that can participate in a redox cycle with the initiator and the growing polymer chain. It is preferred that the transition metal compound not form direct carbon-metal bonds with the polymer chain. Transition metal catalysts useful in the present invention may be represented by the
25 following general formula III,



wherein TM is the transition metal, n is the formal charge on the transition metal having a value of from 0 to 7, and X is a
30 counterion or covalently bonded component. Examples of the transition metal (TM) include, but are not limited to, Cu, Fe, Au, Ag, Hg, Pd, Pt, Co, Mn, Ru, Mo, Nb and Zn. Examples of X include, but are not limited to, halogen, hydroxy, oxygen, C₁-C₆-alkoxy, cyano, cyanato, thiocyanato and azido. A preferred
35 transition metal is Cu(I) and X is preferably halogen, e.g., chloride. Accordingly, a preferred class of transition metal

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catalysts are the copper halides, e.g., Cu(I)Cl. It is also preferred that the transition metal catalyst contain a small amount, e.g., 1 mole percent, of a redox conjugate, for example, Cu(II)Cl₂ when Cu(I)Cl is used. Additional catalysts
5 useful in preparing the epoxy functional polymers of the present invention are described on pages 45 and 46 of international patent publication WO 97/18247. Redox conjugates are described on pages 27 through 33 of international patent publication WO 97/18247.

10 Ligands that may be used in preparing epoxy functional polymers of the present invention, include, but are not limited to compounds having one or more nitrogen, oxygen, phosphorus and/or sulfur atoms, which can coordinate to the transition metal catalyst compound, e.g., through sigma and/or
15 pi bonds. Classes of useful ligands, include but are not limited to: unsubstituted and substituted pyridines and bipyridines; porphyrins; cryptands; crown ethers; e.g., 18-crown-6; polyamines, e.g., ethylenediamine; glycols, e.g., alkylene glycols, such as ethylene glycol; carbon monoxide;
20 and coordinating monomers, e.g., styrene, acrylonitrile and hydroxyalkyl (meth)acrylates. A preferred class of ligands are the substituted bipyridines, e.g., 4,4'-dialkyl-bipyridyls. Additional ligands that may be used in preparing epoxy functional polymers of the present invention are
25 described on pages 46 through 53 of international patent publication WO 97/18247.

In preparing the epoxy functional polymers of the present invention the amounts and relative proportions of initiator, transition metal compound and ligand are those for which ATRP
30 is most effectively performed. The amount of initiator used can vary widely and is typically present in the reaction medium in a concentration of from 10⁻⁴ moles / liter (M) to 3 M, for example, from 10⁻³ M to 10⁻¹ M. As the molecular weight of the epoxy functional polymer can be directly related to the
35 relative concentrations of initiator and monomer(s), the molar ratio of initiator to monomer is an important factor in

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polymer preparation. The molar ratio of initiator to monomer is typically within the range of 10^{-4} : 1 to 0.5 : 1, for example, 10^{-3} : 1 to 5×10^{-2} : 1.

In preparing the epoxy functional polymers of the present invention, the molar ratio of transition metal compound to initiator is typically in the range of 10^{-4} : 1 to 10 : 1, for example, 0.1 : 1 to 5 : 1. The molar ratio of ligand to transition metal compound is typically within the range of 0.1 : 1 to 100 : 1, for example, 0.2 : 1 to 10 : 1.

Epoxy functional polymers useful in the thermosetting compositions of the present invention may be prepared in the absence of solvent, i.e., by means of a bulk polymerization process. Generally, the epoxy functional polymer is prepared in the presence of a solvent, typically water and/or an organic solvent. Classes of useful organic solvents include, but are not limited to, esters of carboxylic acids, ethers, cyclic ethers, C_5 - C_{10} alkanes, C_5 - C_8 cycloalkanes, aromatic hydrocarbon solvents, halogenated hydrocarbon solvents, amides, nitriles, sulfoxides, sulfones and mixtures thereof. Supercritical solvents, such as CO_2 , C_1 - C_4 alkanes and fluorocarbons, may also be employed. A preferred class of solvents are the aromatic hydrocarbon solvents, particularly preferred examples of which are xylene, and mixed aromatic solvents such as those commercially available from Exxon Chemical America under the trademark SOLVESSO. Additional solvents are described in further detail on pages 53 through 56 of international patent publication WO 97/18247.

The epoxy functional polymer is typically prepared at a reaction temperature within the range of $25^\circ C$ to $140^\circ C$, e.g., from $50^\circ C$ to $100^\circ C$, and a pressure within the range of 1 to 100 atmospheres, usually at ambient pressure. The atom transfer radical polymerization is typically completed in less than 24 hours, e.g., between 1 and 8 hours.

When the epoxy functional polymer is prepared in the presence of a solvent, the solvent is removed after the polymer has been formed, by appropriate means as are known to

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those of ordinary skill in the art, e.g., vacuum distillation. Alternatively, the polymer may be precipitated out of the solvent, filtered, washed and dried according to known methods. After removal of, or separation from, the solvent, the epoxy functional polymer typically has a solids (as measured by placing a 1 gram sample in a 110°C oven for 60 minutes) of at least 95 percent, and preferably at least 98 percent, by weight based on total polymer weight.

Prior to use in the thermosetting compositions of the present invention, the ATRP transition metal catalyst and its associated ligand are typically separated or removed from the epoxy functional polymer. Removal of the ATRP catalyst is achieved using known methods, including, for example, adding a catalyst binding agent to the a mixture of the polymer, solvent and catalyst, followed by filtering. Examples of suitable catalyst binding agents include, for example, alumina, silica, clay or a combination thereof. A mixture of the polymer, solvent and ATRP catalyst may be passed through a bed of catalyst binding agent. Alternatively, the ATRP catalyst may be oxidized in situ and retained in the epoxy functional polymer.

The epoxy functional polymer may be selected from the group consisting of linear polymers, branched polymers, hyperbranched polymers, star polymers, graft polymers and mixtures thereof. The form, or gross architecture, of the polymer can be controlled by the choice of initiator and monomers used in its preparation. Linear epoxy functional polymers may be prepared by using initiators having one or two radically transferable groups, e.g., diethyl-2-halo-2-methyl malonate and α,α' -dichloroxylylene. Branched epoxy functional polymers may be prepared by using branching monomers, i.e., monomers containing radically transferable groups or more than one ethylenically unsaturated radically polymerizable group, e.g., 2-(2-bromopropionyloxy)ethyl acrylate, p-chloromethylstyrene and diethyleneglycol bis(methacrylate).

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Hyperbranched epoxy functional polymers may be prepared by increasing the amount of branching monomer used.

Star epoxy functional polymers may be prepared using initiators having three or more radically transferable groups, e.g., hexakis(bromomethyl)benzene. As is known to those of ordinary skill in the art, star polymers may be prepared by core-arm or arm-core methods. In the core-arm method, the star polymer is prepared by polymerizing monomers in the presence of the polyfunctional initiator, e.g., hexakis(bromomethyl)benzene. Polymer chains, or arms, of similar composition and architecture grow out from the initiator core, in the core-arm method.

In the arm-core method, the arms are prepared separately from the core and optionally may have different compositions, architecture, molecular weight and PDI's. The arms may have different epoxy equivalent weights, and some may be prepared without any epoxy functionality. After the preparation of the arms, they are attached to the core. For example, the arms may be prepared by ATRP using glycidyl functional initiators. These arms can then be attached to a core having three or more active hydrogen groups that are reactive with epoxides, e.g., carboxylic acid or hydroxyl groups. The core can be a molecule, such as citric acid, or a core-arm star polymer prepared by ATRP and having terminal reactive hydrogen containing groups, e.g., carboxylic acid, thiol or hydroxyl groups. The reactive hydrogen groups of the core may react with the residue of the glycidyl functional initiator or with epoxy functionality along the backbone of the arms.

An example of a core prepared by ATRP methods that can be used as a core in an ATRP arm-core star polymer is described as follows. In the first stage, 6 moles of methyl methacrylate are polymerized in the presence of one mole of 1,3,5-tris(bromomethyl)benzene. In the second stage, 3 moles of 2-hydroxyethyl methacrylate are fed to the reaction mixture. Three living ATRP prepared arms of varying or equivalent composition, and each containing a single epoxide

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group, e.g., the residue of an epoxide functional initiator, may be connected to the hydroxy terminated core by reaction between the hydroxy groups of the core and the epoxide group in each of the arms. Residues having oxirane functionality
5 can be introduced into the living arms of the arm-core star polymer by continuing the ATRP process in the presence of oxirane functional ethylenically unsaturated radically polymerizable monomers, e.g., glycidyl methacrylate.

Epoxy functional polymers in the form of graft polymers
10 may be prepared using a macroinitiator, as previously described herein. Graft, branched, hyperbranched and star polymers are described in further detail on pages 79 through 91 of international patent publication WO 97/18247.

The polydispersity index (PDI) of epoxy functional
15 polymers useful in the present invention, is typically less than 2.5, more typically less than 2.0, and preferably less than 1.8, for example, 1.5. As used herein, and in the claims, "polydispersity index" is determined from the following equation: (weight average molecular weight (Mw) /
20 number average molecular weight (Mn)). A monodisperse polymer has a PDI of 1.0. Further, as used herein, Mn and Mw are determined from gel permeation chromatography using polystyrene standards.

General polymer chain structures I and II together or
25 separately represent one or more structures that comprise the polymer chain, or back bone, architecture of the epoxy functional polymer. Subscripts p and q of general polymer chain structures I and II represent average numbers of residues occurring in the M and G blocks of residues
30 respectively. Subscript x represents the number of segments of M and G blocks, i.e., x-segments. Subscripts p and q may each be the same or different for each x-segment. The following are presented for the purpose of illustrating the various polymer architectures that are represented by general
35 polymer chain structures I and II.

Homoblock polymer architecture:

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When x is 1, p is 0 and q is 5, general polymer chain structure I represents a homoblock of 5 G residues, as more specifically depicted by the following general formula IV.

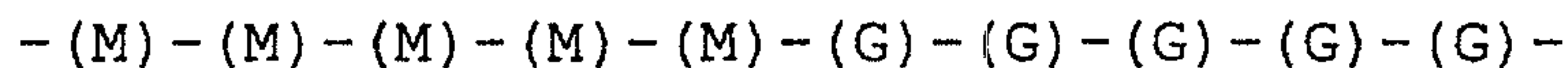
IV



Diblock copolymer architecture:

When x is 1, p is 5 and q is 5, general polymer chain structure I represents a diblock of 5 M residues and 5 G residues as more specifically depicted by the following general formula V.

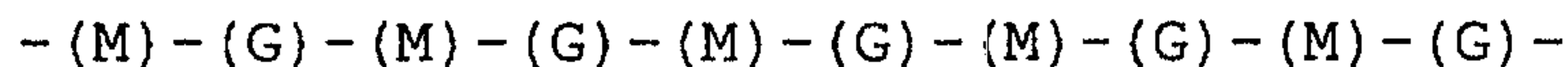
V



15 Alternating copolymer architecture:

When x is greater than 1, for example, 5, and p and q are each 1 for each x-segment, polymer chain structure I represents an alternating block of M and G residues, as more specifically depicted by the following general formula VI.

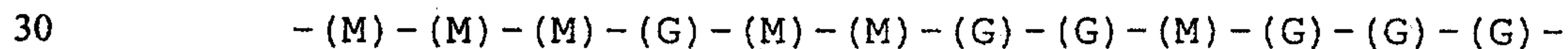
20 VI



Gradient copolymer architecture:

When x is greater than 1, for example, 3, and p and q are each independently within the range of, for example, 1 to 3, for each x-segment, polymer chain structure I represents a gradient block of M and G residues, as more specifically depicted by the following general formula VII.

VII



Gradient copolymers can be prepared from two or more monomers by ATRP methods, and are generally described as having architecture that changes gradually and in a systematic and predictable manner along the polymer backbone. Gradient copolymers can be prepared by ATRP methods by (a) varying the

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ratio of monomers fed to the reaction medium during the course of the polymerization, (b) using a monomer feed containing monomers having different rates of polymerization, or (c) a combination of (a) and (b). Gradient copolymers are described
5 in further detail on pages 72 through 78 of international patent publication WO 97/18247.

With further reference to general polymer chain structures I and II, M represents one or more types of residues that are free of oxirane functionality, and p
10 represents the average total number of M residues occurring per block of M residues (M-block) within an x-segment. The $-(M)_p-$ portion of general structures I and II represents (1) a homoblock of a single type of M residue, (2) an alternating block of two types of M residues, (3) a polyblock of two or
15 more types of M residues, or (4) a gradient block of two or more types of M residues.

For purposes of illustration, when the M-block is prepared from, for example, 10 moles of methyl methacrylate, the $-(M)_p-$ portion of structures I and II represents a
20 homoblock of 10 residues of methyl methacrylate. In the case where the M-block is prepared from, for example, 5 moles of methyl methacrylate and 5 moles of butyl methacrylate, the $-(M)_p-$ portion of general structures I and II represents, depending on the conditions of preparation, as is known to one
25 of ordinary skill in the art: (a) a diblock of 5 residues of methyl methacrylate and 5 residues of butyl methacrylate having a total of 10 residues (i.e., $p = 10$); (b) a diblock of 5 residues of butyl methacrylate and 5 residues of methyl methacrylate having a total of 10 residues; (c) an alternating
30 block of methyl methacrylate and butyl methacrylate residues beginning with either a residue of methyl methacrylate or a residue of butyl methacrylate, and having a total of 10 residues; or (d) a gradient block of methyl methacrylate and butyl methacrylate residues beginning with either residues of
35 methyl methacrylate or residues of butyl methacrylate having a total of 10 residues.

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Also, with reference to general polymer chain structures I and II, G represents one or more types of residues that have oxirane functionality, and q represents the average total number of G residues occurring per block of G residues (G-block). Accordingly, the $-(G)_q-$ portions of polymer chain structures I and II may be described in a manner similar to that of the $-(M)_p-$ portions provided above.

Residue M of general polymer chain structures I and II is derived from at least one ethylenically unsaturated radically polymerizable monomer. As used herein and in the claims, "ethylenically unsaturated radically polymerizable monomer" and like terms are meant to include vinyl monomers, allylic monomers, olefins and other ethylenically unsaturated monomers that are radically polymerizable.

Classes of vinyl monomers from which M may be derived include, but are not limited to, (meth)acrylates, vinyl aromatic monomers, vinyl halides and vinyl esters of carboxylic acids. As used herein and in the claims, by "(meth)acrylate" and like terms is meant both methacrylates and acrylates. Preferably, residue M is derived from at least one of alkyl (meth)acrylates having from 1 to 20 carbon atoms in the alkyl group. Specific examples of alkyl (meth)acrylates having from 1 to 20 carbon atoms in the alkyl group from which residue M may be derived include, but are not limited to, methyl (meth)acrylate, ethyl (meth)acrylate, 2-hydroxyethyl (meth)acrylate, propyl (meth)acrylate, 2-hydroxypropyl (meth)acrylate, isopropyl (meth)acrylate, butyl (meth)acrylate, isobutyl (meth)acrylate, tert-butyl (meth)acrylate, 2-ethylhexyl (meth)acrylate, lauryl (meth)acrylate, isobornyl (meth)acrylate, cyclohexyl (meth)acrylate and 3,3,5-trimethylcyclohexyl (meth)acrylate.

Residue M may also be selected from monomers having more than one (meth)acrylate group, for example, (meth)acrylic anhydride and diethyleneglycol bis((meth)acrylate). Residue M may also be selected from alkyl (meth)acrylates containing

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radically transferable groups, which can act as branching monomers, for example, 2-(2-bromopropionyloxy)ethyl acrylate.

Specific examples of vinyl aromatic monomers from which M may be derived include, but are not limited to, styrene, p-chloromethylstyrene, divinyl benzene, vinyl naphthalene and divinyl naphthalene. Vinyl halides from which M may be derived include, but are not limited to, vinyl chloride and vinylidene fluoride. Vinyl esters of carboxylic acids from which M may be derived include, but are not limited to, vinyl acetate, vinyl butyrate, vinyl 3,4-dimethoxybenzoate and vinyl benzoate.

As used herein and in the claims, by "olefin" and like terms is meant unsaturated aliphatic hydrocarbons having one or more double bonds, such as obtained by cracking petroleum fractions. Specific examples of olefins from which M may be derived include, but are not limited to, propylene, 1-butene, 1,3-butadiene, isobutylene and diisobutylene.

As used herein and in the claims, by "allylic monomer(s)" is meant monomers containing substituted and/or unsubstituted allylic functionality, i.e., one or more radicals represented by the following general formula VIII,

VIII



wherein R_4 is hydrogen, halogen or a C_1 to C_4 alkyl group.

Most commonly, R_4 is hydrogen or methyl and consequently general formula VIII represents the unsubstituted (meth)allyl radical. Examples of allylic monomers include, but are not limited to: (meth)allyl alcohol; (meth)allyl ethers, such as methyl (meth)allyl ether; allyl esters of carboxylic acids, such as (meth)allyl acetate, (meth)allyl butyrate, (meth)allyl 3,4-dimethoxybenzoate and (meth)allyl benzoate.

Other ethylenically unsaturated radically polymerizable monomers from which M may be derived include, but are not limited to: cyclic anhydrides, e.g., maleic anhydride, 1-cyclopentene-1,2-dicarboxylic anhydride and itaconic anhydride; esters of acids that are unsaturated but do not

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have α,β -ethylenic unsaturation, e.g., methyl ester of undecylenic acid; and diesters of ethylenically unsaturated dibasic acids, e.g., diethyl maleate.

Residue G of general polymer chain structures I and II typically is derived from monomers having epoxy, i.e., epoxide or oxirane, functionality. Preferably residue G is derived from at least one of glycidyl (meth)acrylate, 3,4-epoxycyclohexylmethyl (meth)acrylate, 2-(3,4-epoxycyclohexyl)ethyl (meth)acrylate and allyl glycidyl ether.

10 In a particularly preferred embodiment of the present invention, residue G is derived from glycidyl methacrylate. Alternately, epoxy functionality may be incorporated into the epoxy functional polymer by post-reaction, such as by preparing a hydroxyl functional polymer and converting to an

15 epoxy functional polymer by reacting with epichlorohydrin.

Subscripts p and q represent average number of residues occurring in a block of residues in each polymer structure. Typically, p and q each independently have a value of 0 or more, preferably at least 1, and more preferably at least 5

20 for each of general polymer structures I and II. Also, subscripts p and q each independently have a value of typically less than 100, preferably less than 20, and more preferably less than 15 for each of general polymer structures I and II. The values of subscripts p and q may range between

25 any combination of these values, inclusive of the recited values. Moreover, the sum of p and q is at least 1 within an x-segment and q is at least 1 within at least one x-segment in the polymer.

Subscript x of general polymer structures I and II typically has a value of at least 1. Also, subscript x

30 typically has a value of less than 100, preferably less than 50, and more preferably less than 10. The value of subscript x may range between any combination of these values, inclusive of the recited values. If more than one of the structures I

35 and/or II occur in the polymer molecule, x may have different

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values for each structure (as may p and q), allowing for a variety of polymer architectures such as gradient copolymers.

The epoxy functional polymer of the present invention may be further described as having at least one of the following
5 general polymer chain structures IX and X:

IX



and

X



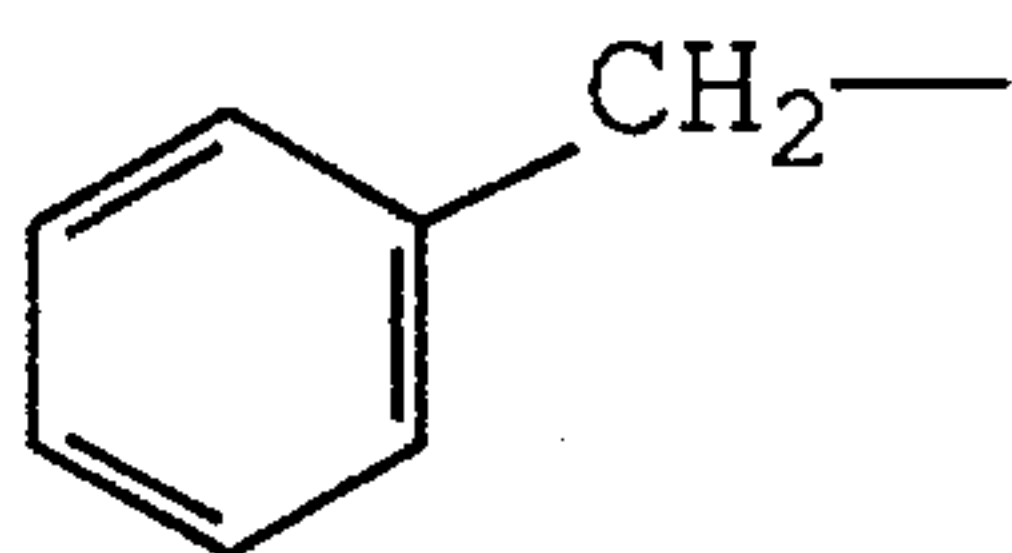
wherein p, q, x, M and G have the same meanings as previously described herein. The subscripts r and s represent average numbers of residues occurring in the respective blocks of M and G residues. The $-(M)_r-$ and $-(G)_s-$ portions of general
15 formulas IX and X have meanings similar to those as previously described herein with regard to portions $-(M)_p-$ and $-(G)_q-$.

The structures IX and X can represent the polymer itself or, alternatively, each of the structures can comprise a terminal segment of the polymer. For example, where z is 1,
20 the structures IX and X can represent a linear polymer, prepared by ATRP using an initiator having 1 radically transferable group. Where z is 2, the structures IX and X can represent a linear "leg" extending from the residue of an initiator having 2 radically transferable groups.
25 Alternatively, where z is greater than 2, the structures IX and X can each represent an "arm" of a star polymer prepared by ATRP, using an initiator having more than 2 radically transferable groups.

Symbol ϕ of general formulas IX and X is or is derived
30 from the residue of the initiator used in the ATRP preparation of the polymer, and is free of the radically transferable group of the initiator. For example, when the epoxy functional polymer is initiated in the presence of benzyl

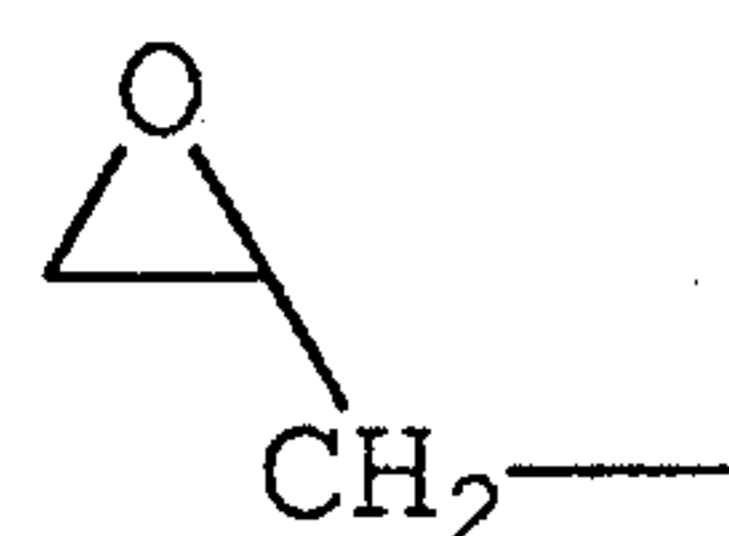
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bromide, the symbol ϕ , more specifically ϕ -, is the benzyl



residue,

The symbol ϕ may also be derived from the residue of the initiator. For example, when the epoxy functional polymer is initiated using epichlorohydrin the symbol ϕ , more



specifically ϕ -, is the 2,3-epoxy-propyl residue,

The 2,3-epoxy-propyl residue can then be converted to, for example, a 2,3-dihydroxypropyl residue. Derivations or conversions of the initiator residue are preferably performed at a point in the ATRP process when loss of epoxide functionality along the polymer backbone is minimal, for example, prior to incorporating a block of residues having epoxy functionality.

In general formulas IX and X, subscript z is equal to the number of epoxy functional polymer chains that are attached to ϕ . Subscript z is at least 1 and may have a wide range of values. In the case of comb or graft polymers, wherein ϕ is a macroinitiator having several pendent radically transferable groups, z can have a value in excess of 10, for example 50, 100 or 1000. Typically, z is less than 10, preferably less than 6 and more preferably less than 5. In a preferred embodiment of the present invention, z is 1 or 2.

Symbol T of general formulas IX and X is or is derived from the radically transferable group of the initiator. For example, when the epoxy functional polymer is prepared in the presence of diethyl-2-bromo-2-methyl malonate, T may be the radically transferable bromo group.

The radically transferable group may optionally be (a) removed or (b) chemically converted to another moiety. In either of (a) or (b), the symbol T is considered herein to be

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derived from the radically transferable group of the initiator. The radically transferable group may be removed by substitution with a nucleophilic compound, e.g., an alkali metal alkoxylate. However, in the present invention, it is desirable that the method by which the radically transferable group is either removed or chemically converted also be relatively mild with regard to the epoxy functionality of the polymer. Many nucleophilic substitution reactions can result in loss of epoxy functionality from the polymer.

10 In a preferred embodiment of the present invention, when the radically transferable group is a halogen, the halogen can be removed by means of a mild dehalogenation reaction, which does not reduce the epoxy functionality of the polymer. The reaction is typically performed as a post-reaction after the polymer has been formed, and in the presence of at least an ATRP catalyst. Preferably, the dehalogenation post-reaction is performed in the presence of both an ATRP catalyst and its associated ligand.

The mild dehalogenation reaction is performed by contacting the halogen terminated epoxy functional polymer of the present invention with one or more ethylenically unsaturated compounds, which are not readily radically polymerizable under at least a portion of the spectrum of conditions under which atom transfer radical polymerizations are performed, hereinafter referred to as "limited radically polymerizable ethylenically unsaturated compounds" (LRPEU compound). As used herein, by "halogen terminated" and similar terms is meant to be inclusive also of pendent halogens, e.g., as would be present in branched, comb and star polymers.

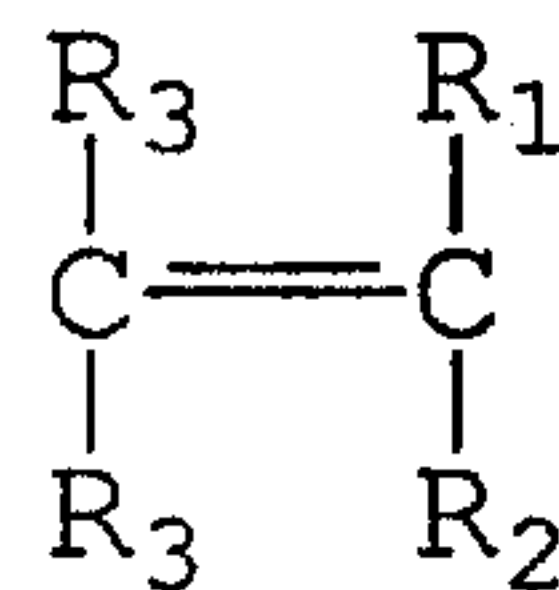
Not intending to be bound by any theory, it is believed, based on the evidence at hand, that the reaction between the halogen terminated epoxy functional polymer and one or more LRPEU compounds results in (1) removal of the terminal halogen group, and (2) the addition of at least one carbon-carbon double bond where the terminal carbon-halogen bond is broken.

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The dehalogenation reaction is typically conducted at a temperature in the range of 0°C to 200°C, e.g., from 0°C to 160°C, a pressure in the range of 0.1 to 100 atmospheres, e.g., from 0.1 to 50 atmospheres. The reaction is also typically performed in less than 24 hours, e.g., between 1 and 8 hours. While the LRPEU compound may be added in less than a stoichiometric amount, it is preferably added in at least a stoichiometric amount relative to the moles of terminal halogen present in the epoxy functional polymer. When added in excess of a stoichiometric amount, the LRPEU compound is typically present in an amount of no greater than 5 mole percent, e.g., 1 to 3 mole percent, in excess of the total moles of terminal halogen.

Limited radically polymerizable ethylenically unsaturated compounds useful for dehalogenating the epoxy functional polymer of the composition of the present invention under mild conditions include those represented by the following general formula XI.

XI



In general formula XI, R₁ and R₂ can be the same or different organic groups such as: alkyl groups having from 1 to 4 carbon atoms; aryl groups; alkoxy groups; ester groups; alkyl sulfur groups; acyloxy groups; and nitrogen-containing alkyl groups where at least one of the R₁ and R₂ groups is an organo group while the other can be an organo group or hydrogen. For instance when one of R₁ or R₂ is an alkyl group, the other can be an alkyl, aryl, acyloxy, alkoxy, arenes, sulfur-containing alkyl group, or nitrogen-containing alkyl and/or nitrogen-containing aryl groups. The R₃ groups can be the same or different groups selected from hydrogen or lower alkyl selected such that the reaction between the terminal halogen of the epoxy functional polymer and the LRPEU compound is not

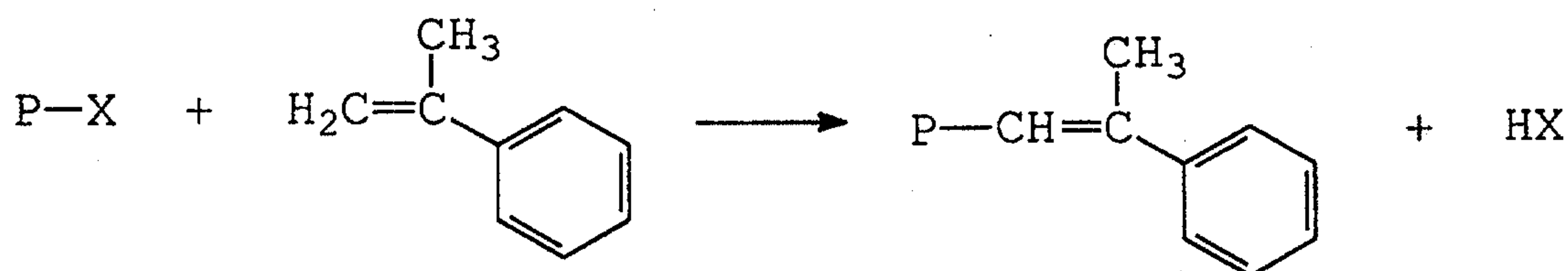
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prevented. Also an R_3 group can be joined to the R_1 and/or the R_2 groups to form a cyclic compound.

It is preferred that the LRPEU compound be free of halogen groups. Examples of suitable LRPEU compounds include, but are not limited to, 1,1-dimethylethylene, 1,1-diphenylethylene, isopropenyl acetate, alpha-methyl styrene, 1,1-dialkoxy olefin and mixtures thereof. Additional examples include dimethyl itaconate and diisobutene (2,4,4-trimethyl-1-pentene).

For purposes of illustration, the reaction between halogen terminated epoxy functional polymer and LRPEU compound, e.g., alpha-methyl styrene, is summarized in the following general scheme 1.

General Scheme 1



In general scheme 1, P-X represents the halogen terminated epoxy functional polymer.

For each of general polymer structures IX and X, the subscripts r and s each independently have a value of 0 or more. Subscripts r and s each independently have a value of typically less than 100, preferably less than 50, and more preferably less than 10, for each of general polymer structures IX and X. The values of r and s may each range between any combination of these values, inclusive of the recited values.

The epoxy functional polymer typically has an epoxy equivalent weight of at least 128 grams / equivalent, and preferably at least 200 grams / equivalent. The epoxy equivalent weight of the polymer is also typically less than 10,000 grams / equivalent, preferably less than 5,000 grams / equivalent, and more preferably less than 1,000 grams / equivalent. The epoxy equivalent weight of the epoxy

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functional polymer may range between any combination of these values, inclusive of the recited values.

The number average molecular weight (Mn) of the epoxy functional polymer is typically at least 250, more typically at least 500, preferably at least 1000, and more preferably at least 2000. The epoxy functional polymer also typically has a Mn of less than 16,000, preferably less than 10,000, and more preferably less than 5,000. The Mn of the epoxy functional polymer may range between any combination of these values, inclusive of the recited values.

The epoxy functional polymer may be used in the thermosetting composition of the present invention as a resinous binder or as an additive with a separate resinous binder, which may be prepared by ATRP or by conventional polymerization methods. When used as an additive, the epoxy functional polymer as described herein typically has low functionality, e.g., it may be monofunctional, and a correspondingly high equivalent weight.

The epoxy functional polymer is typically present in the thermosetting composition of the present invention in an amount of at least 0.5 percent by weight, more typically at least 30 percent by weight, preferably at least 50 percent by weight, and more preferably at least 60 percent by weight, based on total weight of resin solids of the thermosetting composition. The thermosetting composition also typically contains epoxy functional polymer present in an amount of less than 99.5 percent by weight, more typically less than 95 by weight, preferably less than 90 percent by weight, and more preferably less than 80 percent by weight, based on total weight of resin solids of the thermosetting composition. The epoxy functional polymer may be present in the thermosetting composition of the present invention in an amount ranging between any combination of these values, inclusive of the recited values.

The thermosetting composition of the present invention also comprises one or more co-reactants having functional

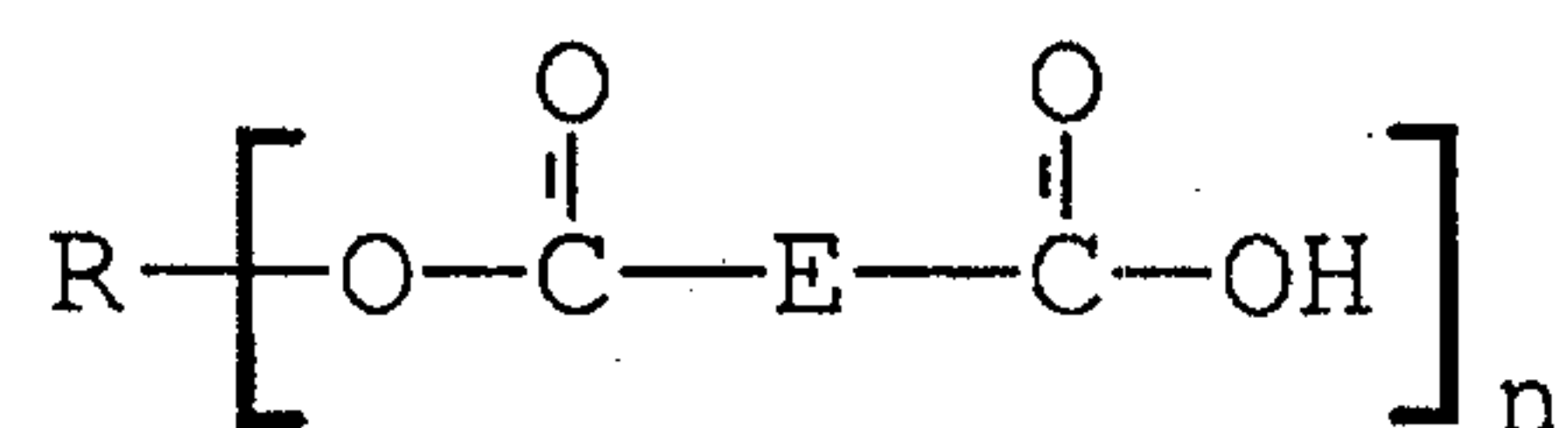
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groups that are reactive with the epoxy functionality of the epoxy functional polymer. The co-reactant (b) of the composition is not prepared by atom transfer radical polymerization methods. The co-reactant may have functional groups selected from the group consisting of hydroxyl, thiol, primary amines, secondary amines, carboxyl and mixtures thereof. Useful co-reactants having amine functionality include, for example, dicyandiamide and substituted dicyandiamides. Preferably, the co-reactant has carboxylic acid groups. In one embodiment of the present invention, the co-reactant has carboxylic acid functionality and is substantially crystalline. By "crystalline" is meant that the co-reactant contains at least some crystalline domains, and correspondingly may contain some amorphous domains. While not necessary, it is preferred that the co-reactant have a melt viscosity less than that of the epoxy functional polymer (at the same temperature). As used herein and in the claims, by "functional groups reactive with the epoxy groups of the epoxy functional polymer" is meant that the co-reactant has at least two functional groups that are reactive with epoxy functionality.

Preferably, the co-reactant is a carboxylic acid functional co-reactant, which typically contains from 4 to 20 carbon atoms. Examples of co-reactants useful in the present invention include, but are not limited to, dodecanedioic acid, azelaic acid, adipic acid, 1,6-hexanedioic acid, succinic acid, pimelic acid, sebacic acid, maleic acid, citric acid, itaconic acid, aconitic acid and mixtures thereof.

Other suitable carboxylic acid functional co-reactants include those represented by the following general formula XII,

XII



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In general formula XII, R is the residue of a polyol, E is a divalent linking group having from 1 to 10 carbon atoms, and n is an integer of from 2 to 10. Examples of polyols from which R of general formula XII may be derived include, but are not limited to, ethylene glycol, di(ethylene glycol), trimethylolethane, trimethylolpropane, pentaerythritol, di-trimethylolpropane, di-pentaerythritol and mixtures thereof. Divalent linking groups from which E may be selected include, but are not limited to, methylene, ethylene, propylene, isopropylene, butylene, pentylene, hexylene, heptylene, octylene, nonylene, decylene, cyclohexylene, e.g., 1,2-cyclohexylene, substituted cyclohexylene, e.g., 4-methyl-1,2-cyclohexylene, phenylene, e.g., 1,2-phenylene, and substituted phenylene, e.g., 4-methyl-1,2-phenylene and 4-carboxylic acid-1,2-phenylene. The divalent linking group E is preferably aliphatic.

The co-reactant represented by general formula XII is typically prepared from a polyol and a dibasic acid or cyclic anhydride. For example, trimethylol propane and hexahydro-4-methylphthalic anhydride are reacted together in a molar ratio of 1 : 3 respectively, to form a carboxylic acid functional co-reactant. This particular co-reactant can be described with reference to general formula XII as follows, R is the residue of trimethylol propane, E is the divalent linking group 4-methyl-1,2-cyclohexylene, and n is 3. Carboxylic acid functional co-reactants described herein with reference to general formula XII are meant to include also any unreacted starting materials and/or co-products, e.g., oligomeric species, resulting from their preparation and contained therein.

The co-reactant is typically present in the thermosetting compositions of the present invention in an amount of at least 10 percent by weight, and preferably at least 15 percent by weight, based on total resin solids weight of the composition. The co-reactant is also typically present in the composition in an amount of less than 70 percent by weight, more typically

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less than 50 percent by weight, preferably less than 30 percent by weight, and more preferably less than 25 percent by weight, based on total resin solids weight of the composition. The amount of co-reactant present in the thermosetting composition of the present invention may range between any combination of these values, inclusive of the recited values.

The equivalent ratio of epoxy equivalents in the epoxy functional polymer (a) to the equivalents of reactive functional groups in the co-reactant (b) is typically from 0.5 : 1 to 2 : 1, and preferably from 0.8 : 1 to 1.5 : 1. While equivalent ratios outside of these ranges are within the scope of the present invention, they are generally less desirable due to appearance and performance deficiencies in cured films obtained therefrom.

The thermosetting composition of the present invention usually also includes one or more cure catalysts for catalyzing the reaction between the reactive functional groups of the co-reactant and the epoxy groups of the polymer. Examples of cure catalysts for acid functional co-reactants are the tertiary amines, e.g., methyl dicocoamine, and tin compounds, e.g., triphenyl tin hydroxide. Curing catalyst is typically present in the thermosetting composition in an amount of less than 5 percent by weight, e.g., from 0.25 percent by weight to 2.0 percent by weight, based on total resin solids weight of the composition.

Thermosetting compositions according to the present invention may optionally include one or more co-curatives that are different than the co-reactant (b), and are not prepared by ATRP methods. As used herein, by "co-curative" is meant a compound that has functionality that is not reactive with the epoxide groups of the epoxy functional polymer (a). For example, the co-curative may have functional groups that are reactive with: the functional groups of the co-reactant (b); and/or the hydroxyl groups formed as a result of reaction between the functional groups of the co-reactant (b) and the epoxide groups of the epoxy function polymer (a). Co-

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curatives may be included in the composition to optimize physical properties (e.g., impact, scratch and crack resistance) of polymerizates obtained therefrom. If used, co-curatives are typically present in the composition in amounts of less than 10 percent by weight, e.g., from 1 to 5 percent by weight, based on total resin solids weight of the thermosetting composition. A useful class of co-curatives are capped polyisocyanates having two or more capped isocyanate groups, which are known to those of ordinary skill in the art. An example of a particularly useful capped polyisocyanate co-curative is a trimer of 1-isocyanato-3-isocyanatomethyl-3,5,5-trimethylcyclohexane (isophorone diisocyanate or IPDI) capped with 2-butanone oxime or ϵ -caprolactam.

The thermosetting composition of the present invention may also include pigments and fillers. Examples of pigments include, but are not limited to, inorganic pigments, e.g., titanium dioxide and iron oxides, organic pigments, e.g., phthalocyanines, anthraquinones, quinacridones and thioindigos, and carbon blacks. Examples of fillers include, but are not limited to, silica, e.g., precipitated silicas, clay, and barium sulfate. When used in the composition of the present invention, pigments and fillers are typically present in amounts of from 0.1 percent to 70 percent by weight, based on total weight of the thermosetting composition. More often, the thermosetting composition of the present invention is used as a clear composition being substantially free of pigments and fillers.

The thermosetting composition of the present invention may optionally contain additives such as waxes for flow and wetting, degassing additives such as benzoin, adjuvant resin to modify and optimize coating properties and ultraviolet (UV) light absorbers. These optional additives, when used, are typically present in amounts up to 20 percent by weight, based on total weight of resin solids of the thermosetting composition.

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The thermosetting composition of the present invention is typically prepared by first dry blending the epoxy functional polymer, the co-reactant and additives, such as flow control agents, degassing agents and catalysts, in a blender, e.g., a
5 Henshel blade blender. The blender is operated for a period of time sufficient to result in a homogenous dry blend of the materials charged thereto. The homogenous dry blend is then melt blended in an extruder, e.g., a twin screw co-rotating extruder, operated within a temperature range of 80°C to
10 140°C, e.g., from 100°C to 125°C.

Optionally, the thermosetting composition may be melt blended in two or more steps. For example, a first melt blend is prepared in the absence of cure catalyst. A second melt blend is prepared at a lower temperature, from a dry blend of
15 the first melt blend and the cure catalyst. When used as a powder coating composition, the melt blended thermosetting composition is typically milled to an average particle size of from, for example, 15 to 30 microns.

In accordance with the present invention there is also
20 provided, a method of coating a substrate comprising:

- (a) applying to said substrate a thermosetting composition;
- (b) coalescing said thermosetting composition to form a substantially continuous film; and
- 25 (c) curing said thermosetting composition by the application of heat, wherein said thermosetting composition comprises a co-reactable solid, particulate mixture as previously described herein.

The thermosetting composition of the present invention
30 may be applied to the substrate by any appropriate means that are known to those of ordinary skill in the art. Generally, the thermosetting composition is in the form of a dry powder and is applied by spray application. Alternatively, the powder can be slurried in a liquid medium such as water, and
35 spray applied. Where the language "co-reactable solid, particulate mixture" is used in the specification and claims,

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the thermosetting composition can be in dry powder form or in the form of a slurry.

When the substrate is electrically conductive, the thermosetting composition is typically electrostatically applied. Electrostatic spray application generally involves drawing the thermosetting composition from a fluidized bed and propelling it through a corona field. The particles of the thermosetting composition become charged as they pass through the corona field and are attracted to and deposited upon the electrically conductive substrate, which is grounded. As the charged particles begin to build up, the substrate becomes insulated, thus limiting further particle deposition. This insulating phenomenon typically limits the film build of the deposited composition to a maximum of 3 to 6 mils (75 to 150 microns).

Alternatively, when the substrate is not electrically conductive, for example as is the case with many plastic substrates, the substrate is typically preheated prior to application of the thermosetting composition. The preheated temperature of the substrate is equal to or greater than that of the melting point of the thermosetting composition, but less than its cure temperature. With spray application over preheated substrates, film builds of the thermosetting composition in excess of 6 mils (150 microns) can be achieved, e.g., 10 to 20 mils (254 to 508 microns). Substrates that may be coated by the method of the present invention include, for example, ferrous substrates, aluminum substrates, plastic substrates, e.g., sheet molding compound based plastics, and wood.

After application to the substrate, the thermosetting composition is then coalesced to form a substantially continuous film. Coalescing of the applied composition is generally achieved through the application of heat at a temperature equal to or greater than that of the melting point of the composition, but less than its cure temperature. In

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the case of preheated substrates, the application and coalescing steps can be achieved in essentially one step.

The coalesced thermosetting composition is next cured by the application of heat. As used herein and in the claims, by
5 "cured" is meant a three dimensional crosslink network formed by covalent bond formation, e.g., between the reactive functional groups of the co-reactant and the epoxy groups of the polymer. The temperature at which the thermosetting composition of the present invention cures is variable and
10 depends in part on the type and amount of catalyst used. Typically, the thermosetting composition has a cure temperature within the range of 130°C to 160°C, e.g., from 140°C to 150°C.

In accordance with the present invention there is further
15 provided, a multi-component composite coating composition comprising:

(a) a base coat deposited from a pigmented film-forming composition; and

(b) a transparent top coat applied over said base
20 coat, wherein said transparent top coat is deposited from a clear film-forming thermosetting composition comprising a co-reactable solid, particulate mixture as previously described herein. The multi-component composite coating composition as described herein is commonly referred to as a color-plus-clear
25 coating composition.

The pigmented film-forming composition from which the base coat is deposited can be any of the compositions useful in coatings applications, particularly automotive applications in which color-plus-clear coating compositions are extensively
30 used. Pigmented film-forming compositions conventionally comprise a resinous binder and a pigment to act as a colorant. Particularly useful resinous binders are acrylic polymers, polyesters including alkyds, and polyurethanes.

The resinous binders for the pigmented film-forming base
35 coat composition can be organic solvent-based materials such as those described in U.S. Patent No. 4,220,679, note column 2

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line 24 through column 4, line 40. Also, water-based coating compositions such as those described in U.S. Patents 4,403,003, 4,147,679 and 5,071,904 can be used as the binder in the pigmented film-forming composition.

5 The pigmented film-forming base coat composition is colored and may also contain metallic pigments. Examples of suitable pigments can be found in U.S. Patents 4,220,679, 4,403,003, 4,147,679 and 5,071,904.

10 Ingredients that may be optionally present in the pigmented film-forming base coat composition are those which are well known in the art of formulating surface coatings and include surfactants, flow control agents, thixotropic agents, fillers, anti-gassing agents, organic co-solvents, catalysts, and other customary auxiliaries. Examples of these optional
15 materials and suitable amounts are described in the aforementioned U.S. Patents 4,220,679, 4,403,003, 4,147,769 and 5,071,904.

20 The pigmented film-forming base coat composition can be applied to the substrate by any of the conventional coating techniques such as brushing, spraying, dipping or flowing, but are most often applied by spraying. The usual spray techniques and equipment for air spraying, airless spray and electrostatic spraying employing either manual or automatic methods can be used. The pigmented film-forming composition
25 is applied in an amount sufficient to provide a base coat having a film thickness typically of 0.1 to 5 mils (2.5 to 125 microns) and preferably 0.1 to 2 mils (2.5 to 50 microns).

30 After deposition of the pigmented film-forming base coat composition on to the substrate, and prior to application of the transparent top coat, the base coat can be cured or alternatively dried. In drying the deposited base coat, organic solvent and/or water, is driven out of the base coat film by heating or the passage of air over its surface. Suitable drying conditions will depend on the particular base
35 coat composition used and on the ambient humidity in the case of certain water-based compositions. In general, drying of

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the deposited base coat is performed over a period of from 1 to 15 minutes and at a temperature of 21°C to 93°C.

The transparent top coat is applied over the deposited base coat by any of the methods by which powder coatings are known to be applied. Preferably the transparent top coat is applied by electrostatic spray application, as described previously herein. When the transparent top coat is applied over a deposited base coat that has been dried, the two coatings can be co-cured to form the multi-component composite coating composition of the present invention. Both the base coat and top coat are heated together to conjointly cure the two layers. Typically, curing conditions of 130°C to 160°C for a period of 20 to 30 minutes are employed. The transparent top coat typically has a thickness within the range of 0.5 to 6 mils (13 to 150 microns), e.g., from 1 to 3 mils (25 to 75 microns).

The present invention is more particularly described in the following examples, which are intended to be illustrative only, since numerous modifications and variations therein will be apparent to those skilled in the art. Unless otherwise specified, all parts and percentages are by weight.

Synthesis Examples A - D

Synthesis Examples A - D describe the preparation of epoxy functional acrylic polymers that are used in the powder coating compositions of Examples 1 - 4. The epoxy functional polymer of Example A is a comparative polymer prepared by non-living radical polymerization. The epoxy functional polymers of Examples B - D are representative of polymers useful in the thermosetting coating compositions of the present invention. The physical properties of the polymers of Examples A - D are summarized in Table 1.

In synthesis Examples A - D, the following monomer abbreviations are used: glycidyl methacrylate (GMA); iso-butyl methacrylate (IBMA); and iso-bornyl methacrylate (IBoMA). The molar ratio of GMA to IBMA to IBoMA was 6 : 4 : 2 in each of

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Synthesis Examples A - D. The block copolymer structures shown in each of Examples B - D are representative general block copolymer formulas.

5

Example A

A comparative epoxy functional polymer was prepared by standard, i.e., non-controlled or non-living, radical polymerization from the ingredients enumerated in Table A.

10

Table A		
Ingredients		Parts by weight
	<u>Charge 1</u>	
xylene		1199.3
15	<u>Charge 2</u>	
GMA		2183.3
IBoMA		1164.4
IBMA		1504.0
	<u>Charge 3</u>	
20 xylene		443.1
initiator (a)		485.2
	<u>Charge 4</u>	
xylene		186.7
	<u>Charge 5</u>	
25 xylene		23.1
initiator (a)		23.1

30 (a) LUPERSOL 555-M60 t-amyl peroxyacetate free radical initiator (60% by weight in odorless mineral spirits), available from Elf-Atochem North America, Inc.

Charge 1 was heated to reflux temperature at atmospheric pressure under a nitrogen blanket in a 12 liter round bottom flask equipped with a rotary blade agitator, reflux condenser, 35 thermometer and heating mantle coupled together in a feed-back loop through a temperature controller, nitrogen inlet port, and two addition ports. While under conditions of reflux, Charges 2 and 3 were concurrently fed into the flask over a

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period of 3 hours and 3.5 hours respectively. With the addition of Charges 2 and 3 complete, Charge 4 was divided into two equal parts and used to rinse any residual material remaining in the addition funnels of Charges 2 and 3 into the flask. Charge 5 was then fed into the flask, followed by a two hour hold under reflux conditions. The contents of the flask were then vacuum stripped. While still molten, the stripped contents of the flask were transferred to a suitable shallow open container and allowed to cool to room temperature and harden.

Example B

An epoxy functional pentablock copolymer useful in the thermosetting compositions of the present invention was prepared by atom transfer radical polymerization from the ingredients listed in Table B. The epoxy functional block copolymer of this example is summarized diagrammatically as follows:

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		Table B	
		Ingredients	Parts by weight
5		<u>Charge 1</u>	
		toluene	158.8
		copper(II) bromide (b)	10.9
		copper powder (c)	44.5
10		2,2'-bipyridyl	15.31
		diethyl-2-bromo-2-methylmalonate	177.2
		IBMA	198.8
		<u>Charge 2</u>	
		toluene	158.8
15		GMA	298.2
		<u>Charge 3</u>	
		toluene	158.8
		IMBA	198.8
		<u>Charge 4</u>	
20		toluene	158.9
		GMA	298.2
		<u>Charge 5</u>	
		toluene	158.9
		IBoMA	311.2

25

(b) The copper(II) bromide was in the form of flakes and was obtained from Aldrich Chemical Company.

30 (c) The copper powder had an average particle size of 25 microns, a density of 1 gram/cm³, and was obtained commercially from OMG Americas.

35 Charge 1 was heated to and held at 90°C for one hour in a 2 liter 4-necked flask equipped with a motor driven stainless steel stir blade, water cooled condenser, and a heating mantle and thermometer connected through a temperature feed-back control device. The contents of the flask were cooled to 70°C and charge 2 was added over a period of 15 minutes, followed by a 1 hour hold at 70°C. The contents of the flask were next

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heated to 90°C and Charge 3 was added over a period of 15 minutes, followed by a 1 hour hold at 90°C. Charge 4 was then added over a period of 15 minutes after cooling the contents of the flask to 70°C, followed by a 1 hour hold at 70°C.

5 After heating the contents of the flask to 90°C, Charge 5 was added over a period of 15 minutes, followed by a 2 hour hold at 90°C. Upon cooling to room temperature, the contents of the flask were filtered and then vacuum stripped. While still molten, the stripped contents of the flask were transferred to

10 a suitable shallow open container and allowed to cool to room temperature and harden.

Example C

An epoxy functional tetrablock copolymer useful in the

15 thermosetting compositions of the present invention was prepared by atom transfer radical polymerization from the ingredients listed in Table C. The epoxy functional block copolymer of this example is summarized diagrammatically as follows:

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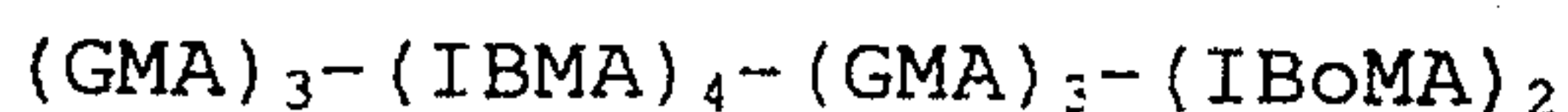


Table C		
Ingredients		Parts by weight
5	<u>Charge 1</u>	
	toluene	158.8
	copper(II) bromide (b)	10.9
	copper powder (c)	44.5
10	2,2'-bypyridyl	15.31
	diethyl-2-bromo-2-methylmalonate	177.2
	GMA	298.2
	<u>Charge 2</u>	
	toluene	158.9
15	IBMA	398.2
	<u>Charge 3</u>	
	toluene	158.9
	GMA	298.2
	<u>Charge 4</u>	
20	toluene	158.9
	IBoMA	311.2

Charge 1 was heated to and held at 70°C for one hour in a 2 liter 4-necked flask equipped as described in Example B.

25 The contents of the flask were heated to 90°C, and Charge 2 was added over a period of 15 minutes, followed by a 1.5 hour hold at 90°C. After cooling the contents of the flask to 70°C, Charge 3 was added over a period of 15 minutes, followed by a 1 hour hold at 70°C. Upon heating the contents of the

30 flask to 90°C, Charge 4 was added over a period of 15 minutes, followed by a 2 hour hold at 90°C. The contents of the flask were cooled, filtered and vacuum stripped as described in Example B.

35

Example D

An epoxy functional hexablock copolymer useful in the thermosetting compositions of the present invention was

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prepared by atom transfer radical polymerization from the ingredients enumerated in Table D. The epoxy functional block copolymer of this example is summarized diagrammatically as follows:

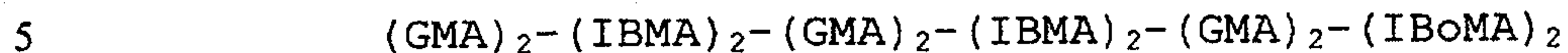


Table D		
	Ingredients	Parts by weight
10	<u>Charge 1</u>	
	toluene	127.0
	copper(II) bromide (b)	10.9
	copper powder (c)	44.5
	2,2'-bipyridyl	15.31
15	diethyl-2-bromo-2-methylmalonate	177.2
	GMA	198.8
	<u>Charge 2</u>	
	toluene	127.0
	IBMA	199.1
20	<u>Charge 3</u>	
	toluene	127.0
	GMA	198.8
	<u>Charge 4</u>	
	toluene	127.0
25	IMBA	199.1
	<u>Charge 5</u>	
	toluene	127.0
	GMA	198.8
	<u>Charge 6</u>	
30	toluene	127.0
	IBoMA	311.2

Charge 1 was heated to and held at 70°C for one hour in a 2 liter 4-necked flask equipped as described in Example B.

35 The contents of the flask were heated to 90°C and Charge 2 was added over a period of 15 minutes, followed by a 1 hour hold at 90°C. Upon cooling the contents of the flask to 70°C,

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Charge 3 was added over 15 minutes and then held at 70°C for 1 hour. After heating the contents of the flask to 90°C, Charge 4 was added over 15 minutes and then held at 90°C for 1 hour. The contents of the flask were cooled to 70°C and Charge 5 was added over 15 minutes followed by a 1 hour hold at 70°C. Upon heating the contents of the flask to 90°C, Charge 6 was added over 15 minutes followed by a hold at 90°C for 2 hours. The contents of the flask were cooled, filtered and vacuum stripped as described in Example B.

10

Table 1
Physical Data of the
Polymers of Synthesis Examples A - D

	Example A	Example B	Example C	Example D
Mn (d)	1369	2448	2087	2300
Mw	2873	3538	2803	3482
Mz	4588	4689	3477	4642
Mp	2927	3499	2986	3622
PDI (e)	2.1	1.4	1.3	1.5
Tg midpoint (°C) (f)	25.3	41.3	43.9	34.2
Melt Viscosity at 125°C (poise) (g)	129	655	689	467
Melt Viscosity at 130°C (Poise)	90	439	461	323
Melt Viscosity at 135°C (poise)	64	286	296	213
Melt Viscosity at 140°C (poise)	48	190	194	146
Melt Viscosity at 145°C (poise)	36	131	133	103
Melt Viscosity at 150°C (poise)	28	87	87	71
Epoxy Equivalent Weight (h)	327	370	330	390
Percent Weight Solids (i)	99.6	99.6	99.5	99.6

15

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(d) The molecular weight data was obtained by means of gel permeation chromatography using polystyrene standards. The abbreviations are summarized as follows: number average molecular weight (Mn); weight average molecular weight (Mw); z average molecular weight (Mz); and peak molecular weight (Mp).

(e) Polydispersity index (PDI) = (Mw/Mn).

(f) Glass transition temperature (Tg) midpoints was determined by means of differential scanning calorimetry. The polymer samples underwent a stress release cycle followed by heating at a rate of 10°C/minute.

(g) Melt viscosities at 125°C through 150°C were determined using a Brookfield CAP 2000 Hight Temperature Viscometer.

(h) Epoxy equivalent weight (grams of polymer/epoxy equivalent) were determined by titration using a 0.1 Normal perchloric acid solution.

(i) Percent weight solids, based on total weight was determined from 0.2 gram samples at 110°C / 1 hour.

Powder Coating Examples 1 - 4

Powder coating Examples 2 - 4 are representative of thermosetting coating compositions according to the present invention, while powder coating Example 1 is a comparative example. The powder coating compositions were prepared from the ingredients enumerated in Table 2.

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Table 2
Powder Coating Compositions

Ingredient	Example 1	Example 2	Example 3	Example 4
Polymer of Example A	682.0	0	0	0
Polymer of Example B	0	715.2	0	0
Polymer of Example C	0	0	715.2	0
Polymer of Example D	0	0	0	715.2
DDDA (j)	236.3	203.1	203.1	203.1
Flow Control Agent (k)	10.0	10.0	10.0	10.0
Benzoin	2.0	2.0	2.0	2.0
Wax (l)	6.0	6.0	6.0	6.0
UV Stabilizer-1 (m)	20.0	20.0	20.0	20.0
UV Stabilizer-2 (n)	20.0	20.0	20.0	20.0
Anti-yellowing additive (o)	20.0	20.0	20.0	20.0
Amine Catalyst (p)	3.7	3.7	3.7	3.7

(j) dodecanedioic acid.

(k) A 100 percent weight solids acrylic flow additive prepared from the non-living free radical polymerization of N,N-dimethylaminoethyl methacrylate, iso-butyl acrylate and 2-ethylhexyl acrylate.

(l) WAX C MICRO POWDER additive available commercially from Hoechst-Celanese, which describes it as ethylene bis-steroylamide.

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(m) TINUVIN 144 ultraviolet light stabilizer available commercially from Ciba-Geigy Corp., which describes it as 2-tert-butyl-2-(4-hydroxy-3,5-di-tert-butylbenzyl)[bis(methyl-2,2,6,6-tetramethyl-4-piperidinyl)]dipropionate.

5

(n) CGL-1545 ultraviolet light stabilizer available commercially from Ciba-Geigy Corp., which describes it as 2-[4((2-hydroxy-3-(2-ethylhexyloxy)propyl)-oxy)-2-hydroxyphenyl)-4,6-bis(2,4-dimethylphenyl)-1,3,5-triazine.

10

(o) GCA-1 anti-yellowing agent commercially available from Sanko Chemical Corp.

*

(p) ARMEEN^{*} M2C amine catalyst available commercially from Akzo-Nobel Corp., which describes it as methyl dicocoamine.

15

The ingredients listed in Table 2 were pre-blended in a Henshel dry blender for 30 to 60 seconds. The pre-blends were then melt-blended in a Werner & Pfleider co-rotating twin screw extruder at a screw speed of 450 revolutions per minute to form a molten extrudate having a temperature of 100°C to 125°C. The molten extrudate was pressed into a thin sheet, cooled and solidified on a set of chilled stainless steel rollers, broken into smaller chips, milled and classified to form thermosetting clear powder coating compositions having an average particle size of from 17 to 27 microns.

20

25

The clear powder coating compositions of Examples 1 - 4 were applied by electrostatic spray application over test panel substrates, and cured at 145°C from 30 minutes. The test panel substrates had been previously coated with a cured black electrocoat primer available from PPG Industries, Inc. as ED-5051 electrophimer. The applied powder coating compositions had cured film thicknesses of from 66 to 74 microns. The appearance of the powder coated test panels was evaluated, and the results are summarized in Table 3.

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Table 3
Appearance of
Powder Coating Examples 1 - 4

	Example 1	Example 2	Example 3	Example 4
20° Gloss Value (q)	84	84	83	84
Longwave Value (r)	1.1	1.5	0.9	1.0
Tension Value (s)	19.2	18.7	19.4	19.2

(q) 20° gloss values were obtained using a BYK Gardner Haze-Gloss Meter in accordance with the manufacturer's suggested method of operation.

(r) Longwave values were obtained using a BYK Wavescan Plus instrument in accordance with the manufacturer's suggested method of operation. Longwave values of lesser magnitude are indicative of coatings that are smoother in appearance.

(s) Tension values were obtained using a BYK Wavescan Plus instrument in accordance with the manufacturer's suggested method of operation. Tension values of greater magnitude are indicative of coatings that are smoother in appearance.

The results as summarized in Table 3 shows that thermosetting powder coating compositions according to the present invention, i.e., Examples 2, 3 and 4, provide coatings having appearance that is similar to that of coatings obtained from comparative compositions, i.e., Example 1. In addition, the powder coating compositions of Examples 2, 3 and 4 were observed to have good room temperature physical stability, i.e., they remained free flowing and showed no signs of sintering or clumping after 24 hours. However, the comparative powder coating composition of Example 1 was observed to have very poor room temperature physical stability

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(becoming sintered, clumped and nearly solid in less than 24 hours).

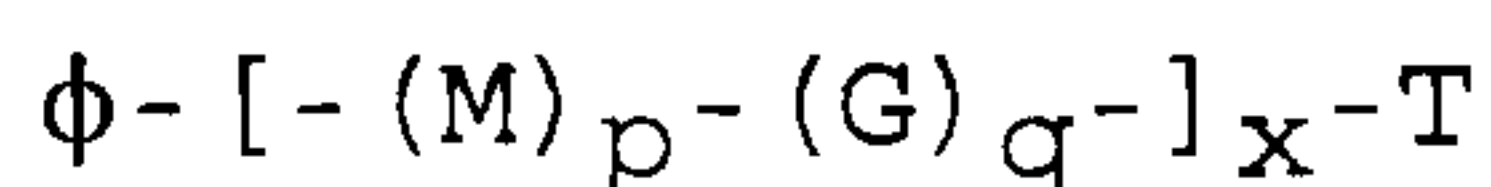
The present invention has been described with reference to specific details of particular embodiments thereof. It is
5 not intended that such details be regarded as limitations upon the scope of the invention except insofar as and to the extent that they are included in the accompanying claims.

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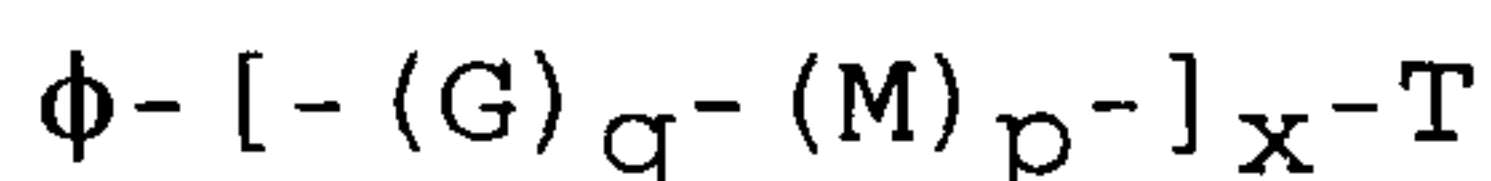
CLAIMS:

1. A thermosetting composition comprising a co-reactable solid, particulate mixture of:

(a) a block epoxy functional copolymer prepared by atom transfer radical polymerization initiated in the presence of an initiator having at least one radically transferable group, and in which said epoxy functional polymer contains at least one of the following polymer chain structures:



and



wherein M is a residue, that is free of oxirane functionality, of at least one ethylenically unsaturated radically polymerizable monomer; G is a residue, that has oxirane functionality, of at least one ethylenically unsaturated radically polymerizable monomer; ϕ is or is derived from a residue from the initiator, free from the radically transferable group, selected from the group consisting of linear or branched aliphatic compounds, cycloaliphatic compounds, heterocyclic compounds, sulfonyl compounds, sulfenyl compounds, esters of carboxylic acids, polymeric compounds and mixtures thereof; T is or is derived from the radically transferable group and is selected from the group consisting of halide and a dehalogenation reaction product of a limited radically polymerizable ethylenically unsaturated compound; p and q represent average numbers of residues occurring in a block of residues in each polymer

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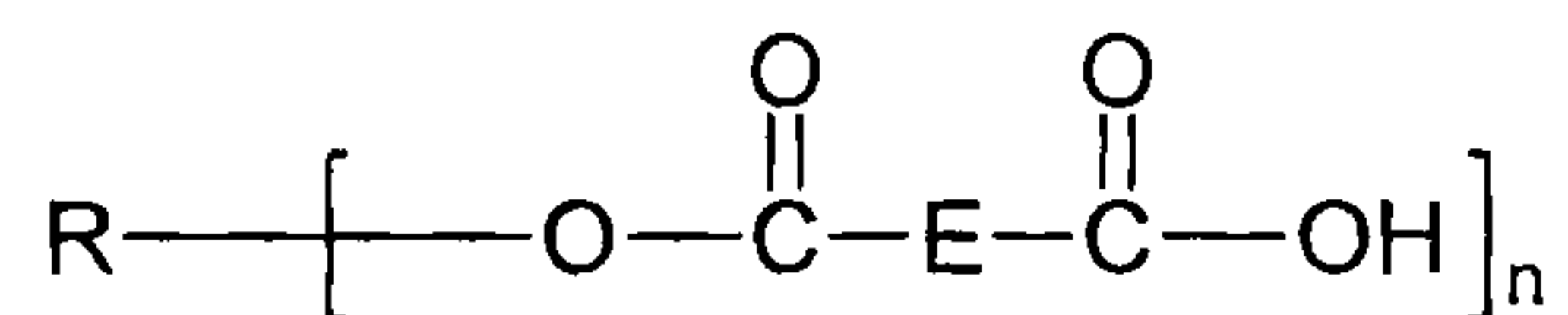
chain structure; p, q and x are each individually selected for each structure such that said epoxy functional polymer has a number average molecular weight of at least 250; a polydispersity of less than 2.5; p is an integer of from 1 to 100; q is an integer of from 1 to 15; and x is an integer of from 1 to 10; and wherein the epoxy functional polymer has an epoxy equivalent weight of from 200 to 1,000 grams/equivalent; and

(b) co-reactant having functional groups reactive with the epoxy groups of (a).

2. The composition of claim 1 wherein said co-reactant is a carboxylic acid functional co-reactant containing from 4 to 20 carbon atoms.

3. The composition of claim 2 wherein said carboxylic acid functional co-reactant is selected from the group consisting of dodecanedioic acid, azelaic acid, adipic acid, 1,6-hexanedioic acid, succinic acid, pimelic acid, sebacic acid, maleic acid, citric acid, itaconic acid, aconitic acid and mixtures thereof.

4. The composition of claim 1 wherein said co-reactant is represented by the following general formula:



wherein R is the residue of a polyol, E is a divalent linking group having from 2 to 10 carbon atoms, and n is an integer of from 2 to 10.

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5. The composition of claim 4 wherein said polyol from which R is derived is selected from the group consisting of ethylene glycol, di(ethylene glycol), trimethylolethane, trimethylolpropane, pentaerythritol, di-trimethylolpropane and di-pentaerythritol; E is selected from the group consisting of 1,2-cyclohexylene and 4-methyl-1,2-cyclohexylene; and n is an integer of from 2 to 6.

6. The composition of claim 1 wherein said epoxy functional polymer is selected from the group consisting of linear polymers, branched polymers, hyperbranched polymers, star polymers, graft polymers, and mixtures thereof.

7. The composition of claim 1 wherein said epoxy functional polymer has a number average molecular weight of from 500 to 16,000, and a polydispersity index of less than 2.0.

8. The composition of claim 1 wherein said initiator is selected from the group consisting of linear or branched aliphatic compounds, cycloaliphatic compounds, aromatic compounds, polycyclic aromatic compounds, heterocyclic compounds, sulfonyl compounds, sulfenyl compounds, esters of carboxylic acids, polymeric compounds and mixtures thereof, each having at least one radically transferable halide.

9. The composition of claim 8 wherein said initiator is selected from the group consisting of halomethane, methylenedihalide, haloform, carbon tetrahalide, 1-halo-2,3-epoxypropane, methanesulfonyl halide, p-toluenesulfonyl halide, methansulfenyl halide, p-toluenesulfenyl halide, 1-phenylethyl halide, C₁-C₆-alkyl ester of 2-halo- C₁-C₆-carboxylic acid, p-halomethylstyrene, mono-hexakis (α -halo-

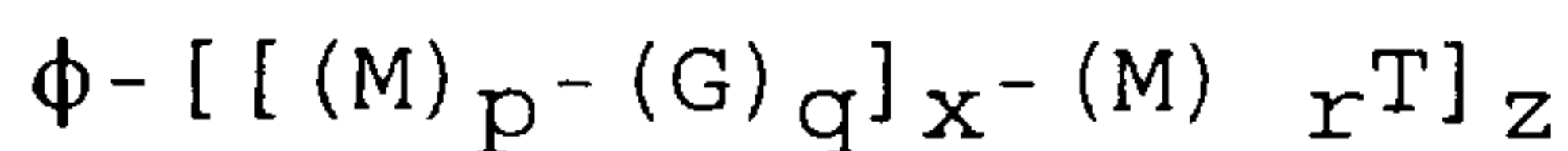
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C₁-C₆-alkyl)benzene, diethyl-2-halo-2-methyl malonate, ethyl 2-bromisobutyrate and mixtures thereof.

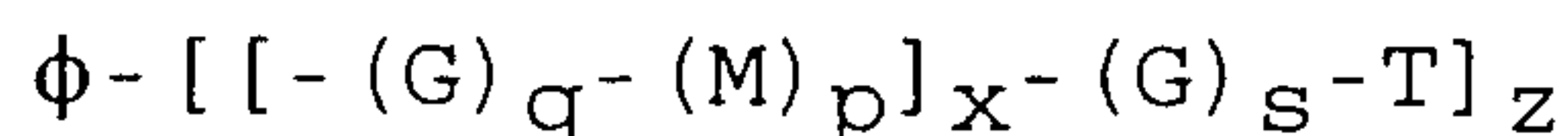
10. The composition of claim 1 wherein M is derived from at least one of vinyl monomers, allylic monomers and olefins.

11. The composition of claim 10 wherein M is derived from at least one of alkyl (meth) acrylates having from 1 to 20 carbon atoms in the alkyl group, vinyl aromatic monomers, vinyl halides, vinyl esters of carboxylic acids and olefins, and G is derived from at least one of glycidyl (meth)acrylate, 3,4-epoxycyclohexyl ethyl(meth)acrylate and allyl glycidyl ether.

12. The composition of claim 1 wherein said epoxy functional polymer has at least one of the following polymer chain structures:



and



wherein M, G, ϕ , T, x, p and q are as defined in claim 1;

the sum of p and q being at least 1 for each x-segment, and q being at least 1 for at least one x-segment; r and s are each independently for each structure within the range of 0 to 100; z is independently for each structure at least 1; and said epoxy functional polymer has a polydispersity index of less than 2.0.

13. The composition of claim 12 wherein T is halide.

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14. The composition of claim 13 wherein T is derived from a dehalogenation post-reaction.

15. The composition of claim 14 wherein said dehalogenation post-reaction comprises contacting said epoxy functional polymer with a limited radically polymerizable ethylenically unsaturated compound.

16. The composition of claim 15 wherein said limited radically polymerizable ethylenically unsaturated compound is selected from the group consisting of 1,1-dimethylethylene, 1,1-diphenylethylene, isopropenyl acetate, alpha-methyl styrene, 1,1-dialkoxy olefin and combinations thereof.

17. The composition of claim 1 wherein the equivalent ratio of epoxy equivalents in said epoxy functional polymer (a) to the equivalents of reactive functional groups in said co-reactant (b) is from 0.5:1 to 2:1.

18. The composition of claim 1 wherein said epoxy functional polymer (a) is present in said thermosetting composition in amounts of from 50 to 90 percent by weight, based on total resin solids weight, and said co-reactant (b) is present in said thermosetting composition in amounts of from 10 to 50 percent by weight, based on total resin solids weight.

19. A method of coating a substrate comprising:

(a) applying to said substrate a thermosetting composition according to any one of claims 1 to 18;

(b) coalescing said thermosetting composition to form a substantially continuous film; and

(c) curing said thermosetting composition by the application of heat.

20. A substrate coated by a method of claim 19.

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21. A multi-component composite coating composition comprising:

(a) a base coat deposited from a pigmented film-forming composition; and

(b) a transparent top coat applied over said base coat, wherein said transparent top coat is deposited from a clear film-forming thermosetting composition according to any one of claims 1 to 18.

22. A substrate having a multi-component composite coating composition of claim 21 deposited thereon.