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**DEFINITIONS OF TERMS RELATING TO THE STRUCTURE  
AND PROCESSING OF INORGANIC AND POLYMERIC GELS  
AND NETWORKS, AND INORGANIC-POLYMERIC  
MATERIALS**

**(IUPAC Recommendations 2005)**

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# Definitions of terms relating to the structure and processing of inorganic and polymeric gels and networks, and inorganic polymeric materials

## (IUPAC Recommendations 2005)

*Abstract:* This document defines terms related to the structure and processing of inorganic, polymeric and hybrid inorganic-polymeric materials from precursors, through gels to solid products. It is divided into four sections, precursors, gels, solids and processes and the terms have been restricted to those most commonly encountered.

For the sake of completeness, and where they are already satisfactorily defined for the scope of this document, terms from other IUPAC publications have been used. Otherwise, the terms and their definitions have been assembled in consultation with experts in the relevant fields. The definitions are intended to assist the reader who is unfamiliar with sol-gel processing, ceramization and related technologies and materials, and to serve as a guide to the use of standard terminology by those researching in these areas.

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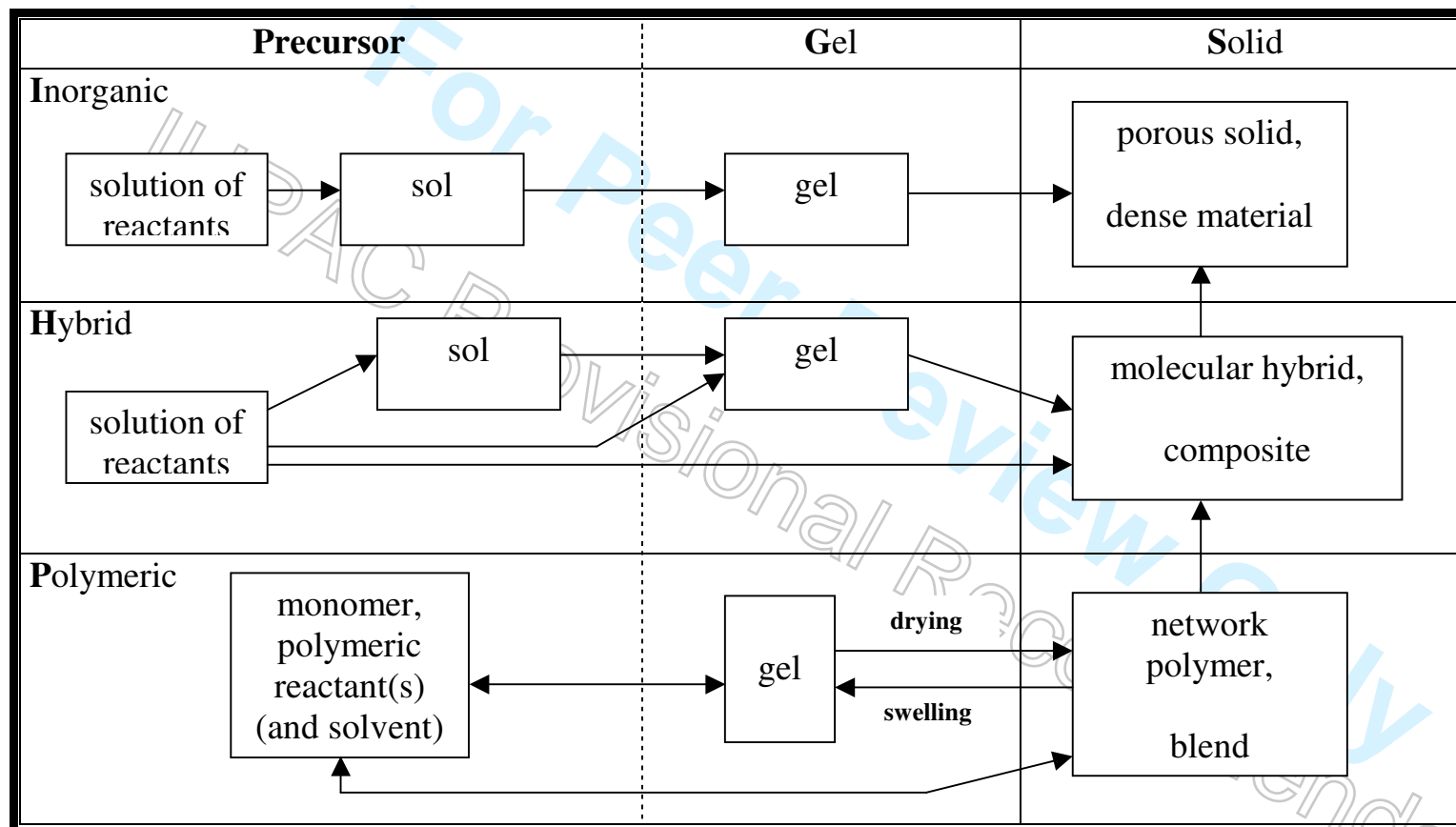
## 1 INTRODUCTION

This document provides definitions of the terms most commonly used in relation to sol-gel processing and ceramization. It embraces all categories of materials and their processing. The definitions result from the efforts of a working party drawn from the membership of the IUPAC Polymer and Inorganic Chemistry Divisions.

As depicted in Figure 1, the various terms relating both to materials and processing can be described within a grid that correlates physical state (liquid, gel and solid) with structural type (inorganic, hybrid and polymeric). Accordingly, the terms in this document are grouped first by state (the columns in Figure 1) and then by state-to-state conversion, i.e., process (the rows in Figure 1). Where it is necessary to indicate or differentiate types of material (inorganic, hybrid, polymer), this has been done within the definition of the relevant term.

For ease of reference, the main terms in each section or sub-section are listed first followed by terms listed alphabetically. All terms are numbered sequentially. Cross references to terms defined elsewhere in the document are denoted in italic typeface. The names of terms defined implicitly in notes to definitions of other terms are written in bold typeface (e.g. **thermoreversible gel** in the note of Definition 3.1.).

For the present document, the terms relating to the structure and mechanical properties of elastomers have been restricted to those that are commonly used, rely on clearly defined theoretical concepts and are unambiguous in their meanings. This area of terminology will be dealt with in more detail in a later document.

**FIGURE 1:****PROJECT SCOPE**

## 2 PRECURSORS

### 2.1 aggregate

#### agglomerate

Clusters of dispersed molecules or particles that result from *agglomeration*. [3]

Note: The term as defined here is specific to polymer science. An alternative definition of “aggregate” is used in some other fields of chemistry (see Definition on p. 13 in [2]).

### 2.2 chemical functionality

#### connectivity

*Recommended symbol: f*

Number of chemical bonds that a monomeric or polymeric reactant can form with other reactants.

Note 1: If  $f = 2$ , a linear chain macromolecule or a macrocycle (see Definition 1.57 in [1]) can be formed.

Note 2: If  $f > 2$ , a branch point can be formed leading to a branched macromolecule, a *network* or a *micronetwork*

### 2.3 colloidal dispersion

#### colloidal suspension

A dispersion of solid particles of size within the colloidal size range.

Note: Adapted from the definition on p.79 in [2].

### 2.4 pre-gel regime

Stage of a network-forming polymerization or crosslinking process extending up to, but not beyond, the gel point.

Note: The pre-gel regime may be expressed as the length of time or the chemical conversion required to reach the gel point from the start of a polymerization or crosslinking process.

### 2.5 pre-gel state

State of a network-forming polymerization or crosslinking process in the pre-gel regime.

Note: In the pre-gel state, the *sol fraction* is equal to unity. All the molecules formed have finite (statistically definable) relative molecular masses.

### 2.6 slip

*Ceramic precursor* in liquid form.

## 2.7 sol

### colloidal sol

Fluid colloidal system of two or more components.

Note 1: See Definition on p.380 in [2].

Note 2: Examples of colloidal sols are protein sols, gold sols, emulsions and surfactant solutions above their critical micelle concentrations.

### 2.7.1 particulate sol

Sol in which the dispersed phase consists of solid particles.

### 2.7.2 sonosol

Particulate sol produced by the action of ultrasonically induced cavitation.

## 2.8 sol fraction

Mass fraction of the soluble material resulting from a network-forming polymerization or crosslinking process that is constituted of molecules of finite (statistically definable) relative molecular masses.

Note: See also *gel fraction*.

## 3 GELS

### 3.1 gel

*Colloidal network* or *polymer network* that is expanded throughout its whole volume by a fluid.

Note : A gel can contain:

- (i) a covalent *polymer network*, e.g., a network formed by crosslinking polymer chains or by non-linear polymerization;
- (ii) a *polymer network* formed through the physical *aggregation* of polymer chains, caused by hydrogen bonds, crystallization, helix formation, complexation, *etc.*, that results in regions of local order acting as the network *junction points*. The resulting swollen network may be termed a **thermoreversible gel** if the regions of local order are thermally reversible;
- (iii) a polymer network formed through glassy *junction points*, e.g., one based on block copolymers. If the *junction points* are thermally reversible glassy domains, the resulting swollen network may also be termed a **thermoreversible gel**;
- (iv) lamellar structures including mesophases, e.g., soap gels, phospholipids and clays;

- (v) particulate disordered structures, e.g., a flocculent precipitate usually consisting of particles of large geometrical anisotropy, such as in V<sub>2</sub>O<sub>5</sub> gels and globular or fibrillar protein gels.

### 3.1.1 aerogel

Microporous solid in which the dispersed phase is a gas.

Note: Many aerogels are of extremely low density. Microporous silica, glass, carbon and zeolites are common examples.

### 3.1.2 alcogel

*Gel* in which the swelling agent consists predominantly of an alcohol or a mixture of alcohols.

### 3.1.3 colloidal gel

*Gel* in which the network component comprises particles of colloidal dimensions.

Note: See also *colloidal network*.

### 3.1.4 hydrogel

*Gel* in which the swelling agent is water.

Note 1: The *network* component of a hydrogel is usually a *polymer network*.

Note 2: A hydrogel in which the *network* component is a *colloidal network* may be referred to as an **aquagel**.

### 3.1.5 microgel

#### gel microparticle

*Gel* of linear dimensions between approximately 0.1 and 100  $\mu\text{m}$ .

### 3.1.6 nanogel

#### gel nanoparticle

*Gel* of linear dimensions between approximately 1 and 100 nm.

### 3.1.7 neutralized gel

*Gel* containing acidic or basic groups that have been neutralized.

### 3.1.8 particulate gel

*Gel* in which the network component comprises solid particles.

Note: The solid particles are often plate-like.



**3.1.9 polyelectrolyte gel**

*Polymer gel* in which the *polymer network* contains ionic or ionizable groups in a significant fraction of its constitutional units.

**3.1.10 polymer gel**

*Gel* in which the network component is a polymer.

**3.1.11 responsive gel**

*Gel* that responds to external electrical, mechanical, thermal, light-induced or chemical stimulation

Note: The use of the term *intelligent gel* is discouraged.

**3.1.12 rheopexic gel  
rheotropic gel**

*Gel* displaying a substantially increased dynamic complex viscosity under the application of stress.

**3.1.13 ringing gel  
humming gel**

*Gel* with energy dissipation in the acoustic frequency range.

Note: A ringing gel is often a *hydrogel* with a surfactant as a third component and has a composition within an isotropic, one-phase region of its ternary phase-diagram.

**3.1.14 sonogel**

*Colloidal gel* produced by the action of ultrasonically induced cavitation.

**3.1.15 thixotropic gel**

*Gel* displaying substantially reduced dynamic complex viscosity under the application of stress.

**3.1.16 xerogel**

*Gel* after removal of all swelling agents.

**3.2 gel point  
gelation point**

Point of *incipient network* formation in a process forming a chemical or physical *polymer network*.

Note 1: In both network-forming polymerization and the crosslinking of polymer chains, the gel point is expressed as an extent of chemical reaction (*c.f.*, *gel time*).

Note 2: At the gel point a solid (network) material spanning the entire system is formed. See also *gel fraction*.

Note 3: The gel point is often detected using rheological methods. Different methods can give different gel points because viscosity is tending to infinity at the gel point and a unique value cannot be measured directly.

### 3.3 gel temperature gelation temperature

Temperature threshold for the formation of a *thermoreversible gel*.

Note: A *thermoreversible gel* is usually formed by cooling a polymer solution. In these cases, the gel temperature is a maximum temperature.

### 3.4 gel time gelation time

Time interval from the start of a network-forming process to the *gel point*.

## 4 SOLIDS

### 4.1 ceramer ormocer

Organically modified ceramic.

### 4.2 ceramic

Rigid material that consists of an infinite three-dimensional *network* of metal or metalloid atoms bonded to carbon, nitrogen or oxygen by covalent bonds.

Note 1: Ceramics are formed from clay-minerals in a pyrolytic process.

Note 2: Examples of ceramics include: silicon oxycarbides, two-phase ceramic materials that are mixtures of SiOC and C and are commonly called **black glasses**; **partially stabilized zirconia (PSZ)**, a two-phase ceramic material that consists of precipitates of tetragonal and/or monoclinic phase, or both, dispersed in a cubic matrix.

**4.3 ceramic precursor****pre-ceramic****pre-ceramic material**

Material that is converted to a ceramic through *pyrolysis*.

Note: Examples include poly(dimethylsilane), poly(carbosilane)s, poly(silazane)s, *etc.*

**4.4 ceramic-reinforced polymer**

Polymer composite consisting of a polymer continuous phase and disperse phase domains of microscopic ceramic particles.

Note: See also Definition 3.2 in [3].

**4.5 ceramic yield**

Mass of ceramic expressed as a percentage of the mass of the precursor used in *ceramization*.

Note: **Theoretical ceramic yield** is the ceramic yield based on the stoichiometry of the *ceramization* process.

**4.6 creep**

Time-dependent change of the dimensions of a material under a constant load.

**4.7 elastomer**

Polymer that displays rubber-like elasticity.

Note: If the polymer comprises a *thermoreversible network* the elastomer is called a **thermoplastic elastomer**.

**4.8 fractal agglomerate**

*Agglomerate* having the same *fractal dimension* as the constituent particles.

**4.9 fractal dimension****mass fractal dimension****Haunsdorf dimension****Recommended symbol:  $d$** 

Parameter that provides a mathematical description of the fractal structure of a *polymer network* or of an aggregated *particulate sol*.

Note 1:  $m \propto r^d$  in which  $m$  is the mass contained within a radius,  $r$ , measured from any site or bond within a fractal structure.

Note 2: For a Euclidian object of constant density,  $d = 3$ , but for a fractal object,  $d < 3$ , such that its density decreases as the object gets larger.

Note 3: For the surface area of a fractal object,  $s \propto r^{d'}$  in which  $s$  is the surface area contained within a radius,  $r$ , measured from any site or bond and  $d'$  is termed the **surface fractal dimension**.

#### 4.10 gel fraction

Mass fraction of the *network* material resulting from a network-forming polymerization or crosslinking process.

Note 1: See also *sol fraction*.

Note 2: The gel fraction comprises a single molecule spanning the entire volume of the material sample.

#### 4.11 green body

Object formed from a *preceramic* material prior to *pyrolysis*.

#### 4.12 hybrid material

Material composed of an intimate mixture of inorganic components, organic components or both types of component.

Note 1: The components usually interpenetrate on scales of less than 1  $\mu\text{m}$ .

Note 2: A hybrid material in which the different components are bonded to each other by covalent or partially covalent bonds is called a **chemically bonded hybrid**.

##### 4.12.1 clay hybrid

###### polymer-clay hybrid

###### polymer-clay composite

Organic-inorganic composite material in which one of the components is a clay, the layers of which are dispersed in a polymer.

#### 4.13 inorganic polymer.

Polymer comprised of macromolecules in which the principal atoms of the backbone are elements other than carbon, nitrogen, oxygen or sulfur.

Note 1: Examples include polyphosphazenes, polysilicates, polysiloxanes, polysilanes, polycarbosilanes, polysilazenes, polygermanes, *etc.*

Note 2: Biopolymers such as DNA, the backbones of which might contain a heteroatom such as phosphorus, would not be classed as inorganic polymers.

**4.14 inter-junction molar mass**

*Recommended symbol:*  $M_c$

*Unit:*  $\text{kg mol}^{-1}$

Number-average molar mass of polymer chains between two adjacent *crosslinks* or *junction points* in a *polymer network*.

**4.15 mixed ceramic**

*Ceramic* material consisting of co-continuous interpenetrating networks of two or more metal carbides or nitrides.

**4.16 monolith**

Fabricated article.

Note: The article is usually fabricated by a processing technique such as cold pressing, hot pressing, *sintering*, moulding, *etc.*

**4.17 multiphase copolymer**

Copolymer comprising phase-separated micro-domains. [3]

**4.18 nanocomposite**

Composite in which at least one of the phase domains has at least one linear dimension of the order of nanometres.

Note: Adapted from Definition 1.15 in [3].

**4.19 network**

Highly ramified structure in which essentially each constitutional unit is connected to each other constitutional unit and to the macroscopic phase boundary by many paths through the structure, the number of such paths increasing with the average number of intervening constitutional units; the paths must on average be co-extensive with the structure.

Note 1: The present definition is generalised from that given in Definition 1.58 in [1] to cover non-polymeric as well as polymeric networks. In the former, the constitutional units can be particles rather than the constitutional units of polymer chains.

Note 2: Usually, and in all systems that exhibit rubber elasticity, the number of distinct paths is very high, but, in most cases, some constitutional units exist which are connected by a single path only.

**4.19.1 colloidal network**

Network that comprises particles of colloidal dimensions.

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5 **4.19.2 polymer network**  
6 **network polymer**  
7

8 Polymer composed of one or more networks.

9 Note: See Definition on p. 271 in [2].  
10

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13 **4.19.2.1 bimodal network**  
14 **bimodal polymer network**  
15

16 *Polymer network* comprising polymer chains having two significantly different molar-mass  
17 distributions between adjacent *junction points*.  
18

19  
20  
21 **4.19.2.2 covalent network**  
22 **covalent polymer network**  
23

24 *Polymer network* in which the permanent paths through the structure are all formed by covalent  
25 bonds.  
26

27  
28  
29 **4.19.2.3 entanglement network**  
30

31 *Polymer network* with junction points or zones formed by physically entangled chains.

32 Note: See also *physical network*.  
33

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36 **4.19.2.4 interpenetrating polymer network**  
37

38 ***Recommended abbreviation: IPN***

39 Assembly of macromolecules comprising two or more networks that are at least partially  
40 interlaced on a molecular scale but not covalently bonded to each other and cannot be separated  
41 unless chemical bonds are broken.  
42

43 Note 1: Adapted from Definitions 2.43 in [1] and 1.18 in [4].

44 Note 2: A mixture of two or more pre-formed polymer networks is not an IPN.

45 Note 3: An IPN can be further described by the process by which it is synthesized. When an IPN  
46 is prepared by a process in which the second component network is polymerized following the  
47 completion of the polymerization of the first component network, the IPN may be referred to as a  
48 **sequential IPN**. When an IPN is prepared by a process in which both component networks are  
49 polymerized concurrently, the IPN may be referred to as a **simultaneous IPN**.  
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57 **4.19.2.5 micronetwork**  
58

59 Polymer network that has dimensions of the order of 1 nm to 1  $\mu\text{m}$ .

60 Note: Adapted from Definition 1.60 in [1]

#### 4.19.2.6 model network

*Polymer network* synthesized using a reactant or reactants of known molar mass or masses and chemical structure.

Note 1: A model network can be prepared using a non-linear polymerization or by crosslinking of existing polymer chains.

Note 2: A model network is not necessarily a *perfect network*. If a non-linear polymerization is used to prepare the network, non-stoichiometric amounts of reactants or incomplete reaction can lead to network chains connected to junction points at only one end. Such a chain is termed **loose end**. If the *crosslinking* of existing polymer chains is used to prepare the network, then two loose ends per existing polymer chain result. In the absence of chain entanglements, loose ends can never be elastically active network chains.

Note 3: In addition to loose ends, model networks usually contain ring structures as network imperfections.

Note 4: Loose ends and ring structures reduce the concentration of elastically active network chains and result in the shear modulus and Young's modulus of the rubbery networks being less than the values expected for a perfect network structure.

Note 5: Physical entanglements between network chains can lead to an increase in the concentration of elastically active network chains and, hence, increases in the shear modulus and the Young's modulus above the values expected for a perfect network structure.

#### 4.19.2.7 oxide network

*Network* comprising only metal-oxygen or metalloid-oxygen linkages.

#### 4.19.2.8 perfect network

##### perfect polymer network

*Polymer network* composed of linear network chains all connected at both of their ends to different junction points.

Note: If a perfect polymer network is in the rubbery state then, on macroscopic deformation of the network, all of its network chains are elastically active and display rubber elasticity.

#### 4.19.2.9 physical network

*Polymer network* with *junction points* or zones formed by physically interacting chains which need not be permanent.

Note 1: The *junction points* or zones need not be permanent over the time scale of the observation or measurement.

Note 2: The interaction can be due to hydrogen bonds,  $\pi$ - $\pi$  interactions, chain entanglements, *etc.*

#### 4.19.2.10 reversible network

*Polymer network* that forms or breaks up as the temperature is changed or under the action of a force.

Note 1: A *polymer network* that forms or breaks up as the temperature is changed is also called a **thermoreversible network**.

Note 2: The *junction points* in a reversible network are usually small crystallites or glassy domains such as those formed within block copolymers.

#### 4.19.2.11 semi-interpenetrating polymer network

**Recommended abbreviation:** SIPN

Assembly of macromolecules comprising one or more polymer networks and one or more linear or branched polymers characterized by the penetration on a molecular scale of at least one of the networks by at least some of the linear or branched macromolecules.

Note 1: Definition 2.42 in [1].

Note 2: A SIPN is distinguished from an *IPN* because the constituent linear or branched macromolecules can, in principle, be separated from the constituent polymer network(s) without breaking chemical bonds and is a polymer blend.

Note 3: A SIPN may further be described by the process by which it is synthesized. When a two-component SIPN is prepared by a process in which a second component polymer is polymerized or incorporated following the completion of the polymerization of a first component, the SIPN may be referred to as a **sequential SIPN**. When a SIPN is prepared by a process in which the components are polymerized concurrently, the SIPN may be referred to as a **simultaneous SIPN**.

#### 4.19.2.12 transient network

*Network* that exists only transiently.

Note: The network structure of a transient polymer network is based on transient *junction points* or *crosslinks* arising from interactions between polymer chains.

#### 4.20 organically modified silicate

**Recommended acronym:** ormosil

*Sol-gel material* obtained by the co-condensation of alkoxy-silanes and hydroxy-terminated polysiloxanes.

Note: An organically modified silicate may further be described as a material in which different silicon precursors are combined to give a general structure  $\text{Si}(\text{OR})_a(\text{B})_b(\text{C})_c(\text{D})_d$ , where  $(a + b + c + d) = 4$ , R can be any alkyl group and A, B and C can be any organic group.



**4.21 polymer alloy**

Macroscopically homogeneous polymeric material that comprises either a compatible polymer blend, a miscible polymer blend or a multiphase copolymer.

Note: Adapted from Definition 1.38 in [3].

**4.22 polymer blend**

Macroscopically homogeneous mixture of two or more different species of polymer.

Note 1: Definition 2.40 in [1] and 1.1 in [3].

Note 2: In most cases, blends are homogeneous on scales larger than several times the wavelengths of visible light.

Note 3: In principle, the constituents of a blend are separable by physical means.

Note 4: No account is taken of the miscibility or immiscibility of the constituent macromolecules, i.e., no assumption is made regarding the number of phase domains present.

Note 5: The use of the term *polymer alloy* for a polymer blend is discouraged, as the former term includes multiphase copolymers but excludes incompatible polymer blends.

Note 6: The number of polymeric components which comprise a blend is often designated by an adjective, *viz.* binary, ternary, quaternary, *etc.*

**4.22.1 compatible polymer blend**

Immiscible polymer blend that exhibits macroscopically uniform physical properties.

Note: The macroscopically uniform properties are usually caused by sufficiently strong interactions between the component polymers.

**4.22.2 homogeneous polymer blend****miscible polymer blend**

Polymer blend that exhibits miscibility.

Note 1: Definition 1.3 in [3].

Note 2: For a polymer blend to be miscible it must obey the thermodynamic criteria of miscibility.

Note 3: Miscibility is sometimes assigned erroneously on the basis that a blend exhibits a single  $T_g$  or is optically clear.

Note 4: The miscible system can be thermodynamically stable or metastable.

Note 5: For components of chain structures that would be expected to be miscible, miscibility may not occur if molecular architecture is changed, e.g., by *crosslinking*.

**4.23 sol-gel material**

Material formed through a *sol-gel process*.

#### 4.23.1 sol-gel coating

Glass-like, transparent coating formed through sol-gel processing.

#### 4.23.2 sol-gel metal oxide

Metal oxide used in *sol-gel processing*.

#### 4.23.3 sol-gel silica

Silica formed through *sol-gel processing*.

### 4.24 Terms Related to Molecular Structure

Terms related to the molecular structure of solids as opposed to those related to the materials themselves are grouped here.

#### 4.24.1 affine chain behaviour

Behaviour of a *polymer network* in which the junction points deform uniformly with the macroscopic deformation of the network.

Note: In reality, affine chain behaviour can apply only at small deformations.

#### 4.24.2 branch point

Point on a polymer chain at which a branch is attached. [1, 2]

Note 1: A branch point from which  $f$  linear chains emanate may be termed an **f-functional branch point**, e.g., five-functional branch point. Alternatively, the terms trifunctional, tetrafunctional, pentafunctional, *etc.* may be used, e.g., pentafunctional branch point.

Note 2: A branch point in a *network* may be termed a *junction point*.

#### 4.24.3 chain entanglement

Physical interaction between polymer chains in a polymer material forming a transient or permanent network junction over the time scale of the observation or measurement.

Note: Types of chain entanglement include the **bowtie entanglement** and the **butterfly entanglement**, these names being descriptive of their topology.

#### 4.24.4 crosslink

Small region in a macromolecule from which at least four chains emanate and which is formed by reactions involving sites or groups on existing macromolecules or by interactions between existing macromolecules [1, 2].

See also *crosslinking*.

Note 1: The small region may be an atom, a group of atoms, a branch point or a number of *branch points* connected by bonds, groups of atoms or oligomeric chains.

Note 2: In the majority of cases, a crosslink is a covalent structure but the term is also used to describe a region of weaker chemical interaction, portions of crystallites or even physical interactions and entanglements.

Note 3: A **permanent crosslink** is a crosslink formed by covalent bonds, intramolecular or intermolecular interactions that are stable under the conditions of use of the material formed.

Note 4: A **transient crosslink** is a crosslink formed by intramolecular or intermolecular interactions that are unstable under the conditions of use of the material formed.

#### 4.24.5 crosslink density

Number of *crosslinks* per unit volume in a *polymer network* formed by reactions involving sites or groups on chains or by interactions between chains.

See also *junction point density*.

#### 4.24.6 crosslinking site

Site on a macromolecule or a small volume in a polymer material that takes part in the formation of chemical or physical *crosslinks*.

#### 4.24.7 elastically active network chain

Segment of a chain between two successive *crosslinks* in a *polymer network* that is long enough to show entropic elasticity.

#### 4.24.8 junction point

*Branch point* in a *polymer network*.

See also Definition 1.54 in [1].

##### 4.24.8.1 thermoreversible junction point

*Junction point* in a polymer network that can be destroyed and formed reversibly by a change of temperature.

##### 4.24.8.2 transient junction point

*Junction point* in a *network* that exists only for a finite period of time.

See also 4.24.3 crosslink, Note 4.

#### 4.24.9 junction point density

Number of *junction points* per unit volume in a *polymer network*.

See also *crosslink density*.

#### 4.24.10 network defect

Elastically ineffective chains in a *polymer network*.

Note: A network defect is caused by a loose end (see *model network*) or a cyclic structure.

#### 4.24.11 phantom chain behaviour

Hypothetical behaviour in which chains can move freely through one another when a *network* is deformed.

## 5 PROCESSES

### 5.1 aerosol hydrolysis

Hydrolysis of the continuous component of an aerosol.

### 5.2 agglomeration aggregation

Process in which dispersed molecules or particles form clusters rather than remain as isolated single molecules or particles.

Note 1: See also Definition on p. 13 of [2].

Note 2: In colloid chemistry, the terms **coagulation** and **flocculation** are synonyms of agglomeration and aggregation. See Definitions on pp. 75 and 158 of [2].

### 5.3 calcination

Process of heating a *polymer network* formed through sol-gel processing in air or oxygen to convert it into an *oxide network*.

Note: Adapted from the definition on p. 51 in [2].

### 5.4 carbo-reduction

Process in which a metal oxide is reduced in the presence of carbon or a carbon-containing compound.

### 5.5 ceramization

Process in which a ceramic precursor is converted into a ceramic.

## 5.6 colloidal processing

*Sol-gel processing* in which a *network* of precipitated colloidal particles is treated by a conventional processing technique, such as cold pressing, hot pressing or *sintering*, in order to produce a ceramic article.

## 5.7 crosslinking

Reaction involving sites or groups on existing macromolecules or an interaction between existing macromolecules that results in the formation of a small region in a macromolecule from which at least four chains emanate [5].

Note 1: See also *crosslink*.

Note 2: The small region may be an atom, a group of atoms, or a number of branch points connected by *bonds*, groups of atoms, or oligomeric chains.

Note 3: A reaction of a reactive chain end of a linear macromolecule with an internal reactive site of another linear macromolecule results in the formation of a branch point, but is not regarded as a crosslinking reaction.

## 5.8 curing

Chemical process of converting a prepolymer or a polymer into a polymer of higher molar mass and connectivity and finally into a *network* [5].

Note 1: See also *vulcanization*.

Note 2: Curing is typically accomplished by chemical reactions induced by heating (**thermal curing**), photo-irradiation (**photo-curing**), or electron-beam irradiation (**EB curing**), or by mixing with a chemical curing agent.

Note 3: Physical aging, crystallization, physical crosslinking and postpolymerization reactions are sometimes referred to as “curing”. Use of the term “curing” in these cases is discouraged.

## 5.9 densification

Removal of impurities and the elimination of pores from a *xerogel* to give a material of as near bulk density as possible.

## 5.10 drying control chemical additive

**Recommended abbreviation:** DCCA

Co-solvent used with alcohol in order to facilitate the rapid drying of *gels* without cracking.

## 5.11 exfoliation

Process by which the layers of a multi-layered structure separate.

**5.12 gel aging**

Time-dependent changes in the chemical or the physical structure and the properties of a *gel*.

Note 1: The aging of a polymer *gel* can involve polymerization, crystallization, formation of glassy phases, formation of *branch points*, *junction points* as well as chain scission and chemical changes to constitutional units of the network chains.

Note 2: The aging of a silicate *gel* can involve *syneresis*, coarsening, ripening and phase transformations.

**5.13 gelation**

Process of passing through the *gel point* to form a *gel* or *network*.

**5.14 hot isostatic pressing  
hipping**

*Isostatic pressing* process carried out at elevated temperatures.

Note 1: The pressurizing fluid used in this process is usually a gas.

Note 2: The temperature is usually in excess of 600 °C.

**5.15 hydrolysis ratio**

*Recommended symbol:  $r_w$*

Molar ratio of water to alcohol used in condensation reactions in the *sol-gel processing* of metal alkoxides.

**5.16 in-situ composite formation**

Process for preparing a polymer composite by (a) forming the filler or reinforcement in an existing polymer or (b) polymerizing monomers in the presence of dispersed filler.

**5.17 intercalation**

Process, generally reversible, that involves the penetration of a host molecular structure by guest species without a major structural modification of the host.

Note: Intercalation can refer to the insertion of a guest species into a one-, two- or three-dimensional host structure.

**5.18 isostatic pressing**

Application of a hydrostatic pressure through a liquid to achieve densification followed by the production of a uniform compact *monolith* through *ceramization* of the densified liquid.

### 5.19 net shaping

Production of an object in, or as close as possible to, its final shape prior to ceramization.

### 5.20 Ostwald ripening

Dissolution of small *sol* particles and their re-deposition on the surfaces of larger particles.

Note 1: Adapted from the definition on p.286 of [2].

Note 2: The process occurs because of the greater solubility of small particles.

### 5.21 peptization deflocculation

The reversal of coagulation or *flocculation*, i.e. the dispersion of *aggregates* to form a colloidal stable suspension or emulsion.

Note 1: See Definition on p. 103 in [2].

### 5.22 precipitation

Formation of particles of a solid material (a precipitate) from a liquid in which the material is present in amounts greater than its solubility.

Note: When precipitation occurs in *sol-gel processing*, *sol* particles have aggregated to a size where gravitational forces cause them to sink or float. Generally, *aggregation* arises from a change in the *sol* that reduces the interparticle repulsion.

### 5.23 pyrolysis

Chemical reaction induced by high temperature.

Note: Generally pyrolysis refers to a thermal process in an inert environment and is commonly used for a high-temperature treatment that converts a ceramic precursor to a ceramic.

### 5.24 reaction injection moulding

**Recommended acronym: RIM**

Reactive polymer processing that produces polymer *monoliths* by low-pressure injection and mixing of low viscosity precursors into moulds.

Note 1: Reaction injection moulding commonly uses two-component precursors that produce *polymer networks* after mixing.

Note 2: The most common mouldings are based on polyurethanes.

Note 3: When materials such as glass fibres are included to increase strength in the moulding the process is called **reinforced reaction injection moulding** (**Recommended abbreviation: RRIM**).

Note 4: See also reaction blending, Definition 1.19 in [5]

**5.25 reactive polymer processing**

Process whereby a polymeric *monolith* is produced through an *in situ* polymerisation or polymer modification reaction.

Note 1: The polymerisation or modification reaction and the transformation of the resulting polymer into a shaped product is accomplished in the same processing equipment.

Note 2: This type of processing is commonly accomplished by extrusion or injection molding.

Note 3: *Reaction injection moulding* and *reinforced reaction injection moulding* are types of reactive polymer processing.

**5.26 sedimentation**

Separation of a dispersed system under the action of a gravitational or centrifugal field according to the different densities of the components.

**5.27 sintering**

Coalescence of solid particles and the progressive elimination of porosity through the application of pressure.

Note 1: In some instances, coalescence also requires heating to temperatures in excess of the melt temperature of the solid particles.

Note 2: The term was originally coined for the process by which fly ash produced in the combustion of fuels such as coal is baked (sintered) at a very high temperature to manufacture cinder blocks and other ceramic products.

**5.28 slip casting**

Procedure in ceramic processing whereby *slip* is contained in a porous plaster mould prior to *pyrolysis*.

**5.29 sol-gel critical concentration****critical concentration**

Concentration of an added electrolyte above which a *particulate sol* undergoes coagulation instead of *gelation*.

**5.30 sol-gel process**

Process through which a *network* is formed in solution by a gradual change of liquid precursor(s) into a *sol*, to a *gel*, and in most cases finally to a dry *network*.

Note: An *inorganic polymer*, e.g., silica gel, or an organic-inorganic hybrid can be prepared by sol-gel processing.



**5.31 sol-gel transition**

(a) Transition of a *sol* to a *gel*.

(b) *Gel point*.

Note: Definition 5.32(a) is adapted from the definition on p. 380 of [2].)

**5.32 supercritical drying of a gel**

Drying of a *gel* using a supercritical fluid.

Note: Since liquid and vapour are indistinguishable in a supercritical fluid, there is no capillary pressure to cause shrinkage and cracking of the pores formed in the *gel*.

**5.33 swelling**

Increase in volume of a *network*, *gel* or solid associated with the uptake of a fluid.

Note: Adapted from the definition on p.410 of [2].

**5.34 syneresis**

Spontaneous shrinkage as bond formation or attraction between particles within a *gel* induces contraction of the network and exudation of liquid from the pores.

Note 1: Adapted from the definition on p.411 of [2].

Note 2: Exudation of the fluid from small regions of a *gel* is termed **microsyneresis**.

**5.35 uniaxial pressing**

Application of pressure in one direction during *ceramization* to achieve densification and the production of a uniform, compact *monolith*.

**5.36 viscous sintering****viscous flow sintering**

*Sintering* process by which it is possible to *densify gels* to *glasses* and *ceramics* at elevated temperatures.

**5.37 vulcanization**

Chemical *crosslinking* of high-molar-mass linear or branched polymers to give a *polymer network*.

Note 1: The *polymer network* formed often displays rubberlike elasticity. However, a high concentration of *crosslinks* can lead to rigid molecules.

Note 2: A classic example of vulcanization is the crosslinking of *cis*-polyisoprene through sulfide bridges in the thermal treatment of natural rubber with sulfur or a sulfur-containing compound.

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