

POLYURETHANE PRODUCTS PRODUCED FROM

ALUMINUM PHOSPHONATE CATALYZED POLYETHEROLS

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BACKGROUND OF THE INVENTION

[001.] This invention relates generally to polyurethane products produced using polyether polyols made in the presence of aluminum phosphonate catalysts and, more particularly, to use of polyetherols having very low unsaturation to make polyurethane foams, coatings, adhesives, sealants, elastomers and other products.

15 [002.] Polyoxyalkylene polyether polyols are well known compounds utilized in the formation of a variety of polyurethane products, such as foams, coatings, adhesives, sealants and elastomers. As a general matter, these polyols are produced by polyoxyalkylation of an initiator molecule with ethylene oxide, propylene oxide, butylene oxides, or mixtures thereof. The initiator molecules contain alkylene oxide-reactive hydrogens like hydroxyls and amines. This oxyalkylation is generally conducted in the presence of a catalyst. The most common catalysts are basic metal catalysts such as sodium hydroxide, potassium hydroxide, or alkali metal alkoxides. One advantage of these base catalysts is that they are inexpensive and readily available. Use of these base catalysts, however, is associated with a range of problems. One of the major problems is that the oxyalkylation with propylene oxide has associated with it a competing rearrangement of the propylene oxide into allyl alcohol, which continually introduces a monohydroxyl-functional molecule. This monohydroxyl-functional molecule is also capable of being oxyalkylated. In addition, it can act as a chain terminator during the reaction with isocyanates to produce the final urethane product. Thus, as the oxyalkylation reaction is continued more of this product, generally measured as the unsaturation content of the polyol, is formed. This leads to reduced functionality of the polyol and a broadening of the molecular weight distribution of the final polyol mixture. The amount of unsaturation content may approach 30 to 40% with unsaturation levels of 0.08 meq/g KOH or higher.

[003.] In an attempt to reduce the unsaturation content of polyols a number of other catalysts have been developed. One such group of catalysts includes the hydroxides formed from rubidium, cesium, barium, and strontium. These catalysts also present a number of problems. The catalysts only slightly reduce the

degree of unsaturation, are much more expensive, and some of them are toxic. Like potassium hydroxide catalysts, these higher molecular weight hydroxide catalysts are known to affect the polyurethane forming reaction, they are generally removed prior to work-up of any polyol for use in polyurethane systems.

[004.] A second line of alternative catalyst development has been formation of double metal cyanide (DMC) catalysts. These catalysts are typically based on zinc hexacyanocobaltate. With the use of DMC catalysts it is possible to achieve unsaturations in the range of 0.003 to 0.010 meq/g KOH. While the DMC catalysts would seem to be highly beneficial they also are associated with a number of difficulties. As a first difficulty there is a relatively high capital cost involved in scaling up of and utilization of DMC catalysts. The catalysts themselves have an extremely high cost compared to the base catalysts. The process of making polyols using DMC is also different from based catalyzed reactions. During use of DMC catalysts there is an initial significant, and often unpredictable, lag time before the catalyst begins catalyzing the reaction. Another difficulty is that ethylene oxide does not add uniformly to growing polymer chains utilizing DMC catalysts. Chain transfer is slow relative to chain growth, so all the ethylene oxide adds to only a few of the polymer chains, leaving the rest unreacted. The result is a polyol of such low quality that it has no commercial value. To add ethylene oxide to a growing chain the DMC catalysts must be replaced with the typical base catalysts, thus adding steps. In addition, it is generally believed that the DMC catalysts should be removed prior to work-up of any polyol for use in polyurethane systems. Finally, polyols generated using DMC catalysts are not mere "drop in" replacements for similar size and functionality polyols produced using the typical base catalysts. Indeed, it has been found that often DMC catalyzed polyols have properties very different from equivalent polyols produced using, for example, potassium hydroxide. It is recognized in the art that polyols made utilizing DMC catalysts contain small amounts of high molecular weight compounds, which can affect utilization of these polyols in polyurethane systems, particularly foaming. The so-called high molecular weight tail has been identified in amounts of greater than 100 ppm and variously described as polymer of molecular weight greater than 50,000 Daltons, see U.S. Patent No. 5,919,988 which is incorporated herein by reference. The presence of the so-called high molecular weight tail in amounts of greater than 300 has been identified as a cause of foam destabilization and collapse.

[005.] Thus, there exists a need for a class of catalysts that can be used for the oxyalkylation of initiator molecules by alkylene oxides that is inexpensive, capable of producing very low unsaturation polyols, does not require removal from the polyol prior to utilization in polyurethane systems, and that produces a polyol having properties that are the same or better than those in a polyol produced using base catalysts. Preferably the new class of catalysts can be used in existing systems and equipment using standard manufacturing conditions.

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SUMMARY OF THE INVENTION

[006.] In general terms, the present invention provides low unsaturation polyetherols produced using an aluminum phosphonate catalyst and provides for their use in polyurethane applications.

[007.] One embodiment the present invention is a polyurethane foam produced according to a process comprising the steps of: providing at least one alkylene oxide; providing at least one initiator molecule having at least one alkylene oxide reactive hydrogen; reacting the at least one alkylene oxide with the at least one initiator molecule in the presence of an aluminum phosphonate catalyst to form a polyether polyol; and reacting the polyether polyol formed in step c) with at least one polyisocyanate in the presence of a blowing agent to form a polyurethane foam.

[008.] Another embodiment of the invention is a composition of matter comprising a polyurethane material, preferably selected from the group consisting of flexible foams, rigid foams, coatings, adhesives, sealants, elastomers and thermoplastics, and aluminum phosphonate catalyst having the general structure of $\text{RPO}-(\text{OAlR}'\text{R}'')_2$ or residues of said aluminum phosphonate catalyst, wherein P represents pentavalent phosphorous; O represents oxygen; Al represents aluminum; R comprises a hydrogen, an alkyl group, or an aryl group; and R' and R'' independently comprise a halide, an alkyl group, an alkoxy group, an aryl group, or an aryloxy group, and/or residues of said aluminum phosphonate. In a further embodiment, said aluminum phosphonate is present at levels of from approximately 0.001 to 5.0 weight percent based on the total weight of the polyurethane. Residues of said aluminum phosphonate catalyst are considered to be aluminum phosphonates salts, often crosslinked through aluminum-oxygen bonds.

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[009.] In a further embodiment, R is a methyl group; and R' and R" independently comprise one of an ethyl group, an ethoxy group, a propyl group, a propoxy group, a butyl group, a butoxy group, a phenyl group, or a phenoxy group.

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[0010.] It is another object of the invention to provide a polyurethane product comprising greater than 0.001 weight percent of aluminum phosphonate catalyst and/or aluminum phosphonate catalyst residues based on the total weight of the polyurethane product, said aluminum phosphonate catalyst having the general structure of $RPO-(OAlR'R'')_2$ wherein: O represents oxygen; P represents pentavalent phosphorous; Al represents aluminum; R comprises a hydrogen, an alkyl group, or an aryl group; and R' and R" independently comprise a halide, an alkyl group, an alkoxy group, an aryl group, or an aryloxy group. In a further embodiment, R is a methyl group; and R' and R" independently comprise one of an ethyl group, an ethoxy group, a propyl group, a propoxy group, a butyl group, a butoxy group, a phenyl group, or a phenoxy group.

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[0011.] It is another object of the invention to provide a polyurethane product formed according to a process comprising the steps of providing at least one alkylene oxide; providing at least one initiator molecule having at least one alkylene oxide reactive hydrogen; providing an aluminum phosphonate catalyst as described herein, preferably in an amount of from 0.1 to 5.0 weight percent based on the total weight of the polyether polyol; reacting the at least one alkylene oxide with the at least one initiator molecule in the presence of an aluminum phosphonate catalyst to form a polyether polyol D) having reactive hydrogens; providing at least one organic polyisocyanate and/or isocyanate pre-polymer E) having functional groups reactive toward said polyether polyol reactive hydrogens; reacting E) with D), and optionally, with additional substances having reactive hydrogens, in the presence of a urethane promoting catalyst; and optionally, blowing agents, cross-linkers, surfactants, fillers, pigments, antioxidants and stabilizers.

[0012.] It is another object of the invention to provide a method of producing a polyurethane product comprising reacting a polyol component comprising at least one polyoxyalkylene polyether polyol produced in the presence of an aluminum phosphonate catalyst, and having an average equivalent weight of from about 100 to about 10,000, and an organic isocyanate in the presence of if desired, a catalyst, a blowing agent, and optionally, cross-linkers, surfactants, flame retardants, fillers, pigments, antioxidants and stabilizers. It is a further object to provide a

method wherein said polyether polyol comprises a styrene acrylonitrile graft polymer polyol dispersion and the foam comprises a flexible foam or a mixture of at least one conventional polyether polyol and a least one graft polymer polyol dispersion and the
5 foam comprises a flexible foam.

[0013.] It is a further object of the invention to provide products according to the above described processes that are selected from the group consisting of flexible foams, rigid foams,
10 coatings, adhesives, sealants, elastomers and thermoplastics.

[0014.] It is an object of the invention to provide a polyurethane elastomer comprising a reaction product of an organic polyisocyanate with a polyol component comprising at least one polyether polyol having an equivalent weight of at least 900 and comprising a reaction product of propylene oxide and a di-hydroxyl functionality initiator molecule in the presence of an aluminum phosphonate catalyst.

20 [0015.] It is an object of the invention to provide a method of producing a polyurethane elastomer comprising reacting a polyol component comprising at least one polyoxyalkylene polyether polyol produced in the presence of an aluminum phosphonate catalyst, and an organic isocyanate in the presence of if desired
25 , one or more chain extenders, and optionally a catalyst, a surfactant, a blowing agent, and an effective amount of an flame retardant where the overall functionality of the polyol component (a) and the chain extenders (c) is less than 2.3; and a product by this process.

30 [0016.] It is an object of the invention to provide a method of producing a polyurethane adhesive comprising reacting a polyol component comprising at least one polyoxyalkylene polyether polyol produced in the presence of an aluminum phosphonate
35 catalyst, and an excess of organic isocyanate in the presence of if desired , one or more chain extenders, and optionally a catalyst, a surfactant, a blowing agent, and an effective amount of an flame retardant, and a product by this process.

40 [0017.] It is an object of the invention to provide a method of producing a polyurethane sealant comprising reacting a polyol component comprising at least one polyoxyalkylene polyether polyol produced in the presence of an aluminum phosphonate catalyst, and an organic isocyanate in the presence of if desired
45 , one or more chain extenders, and optionally a catalyst, a surfactant, a blowing agent, and an effective amount of an flame retardant where the overall functionality of the polyol component

(a) and the chain extenders (c) is greater than 2.3 to 3.0 and a product by this process.

[0018.] It is an object of the invention to provide a method of producing a thermoplastic polyurethane article comprising reacting compounds which are reactive toward isocyanates which comprise a polyol component comprising at least one polyoxyalkylene polyether polyol produced in the presence of an aluminum phosphonate catalyst, said polyol component having an average molecular weight of from 500 to 8000, and an organic isocyanate in the presence of if desired, a catalyst, a blowing agent, and optionally a surfactant, a chain extender, and an effective amount of a flame retardant; where the ratio of the isocyanate groups of the component (b) to the sum of isocyanate-reactive groups of the components (a) and, if used, said chain extender is from approximately 1:0.9 to 1:1.1, and a product by this process.

[0019.] These and other features and advantages of this invention will become more apparent to those skilled in the art from the detailed description of a preferred embodiment.

DETAILED DESCRIPTION OF A PREFERRED EMBODIMENT

[0020.] The present invention discloses use of aluminum phosphonate catalysts to catalyze the oxyalkylation of initiator molecules. Use of this catalyst enables production of polyols having very low unsaturation compared to a similar size polyol produced using typical base catalysts. In addition, other than the very low degree of unsaturation, these polyols have properties that are the same or better than those produced using the typical base catalysts. The aluminum phosphonate catalysts can be synthesized in a very straightforward manner and are inexpensive compared to the other catalysts capable of producing these very low unsaturation polyols. We have also found that aluminum phosphonate catalysts did not have to be removed after formation of the polyol prior to its utilization in polyurethane systems. The aluminum phosphonate catalysts can be readily substituted in existing polyurethane oxyalkylation procedures that utilize base catalysts such as potassium hydroxide with substantially no modifications to the procedure. Unlike the DMC class of catalysts these aluminum phosphonate catalysts exhibit no lag time and are capable of polyoxyalkylation utilizing ethylene oxide.

Synthesis of the aluminum phosphonate catalysts

[0021.] The aluminum phosphonate catalysts of the present invention can be produced by a number of processes, one of which is described in detail below. In general the procedure involves reacting a pentavalent phosphonic acid with a tri-substituted aluminum compound to produce an aluminum phosphonate. The pentavalent phosphonic acids that are suitable have the general structure of $\text{RPO}(\text{OH})_2$, wherein: R represents a hydrogen group, and alkyl group, or an aryl group; P represents a pentavalent phosphorous; O represents oxygen; and H represents hydrogen. Some examples include phosphonic acid, methylphosphonic acid, ethylphosphonic acid, propylphosphonic acid, i- t- or sec- butylphosphonic acids, and phenylphosphonic acid. The tri-substituted aluminum compounds have the general structure of AlR'_3 , wherein R' is a methyl group, an alkyl group, an alkoxy group, an aryl group, or an aryloxy group. Some examples include trimethylaluminum, triethylaluminum, triethoxyaluminum, tri-n-propylaluminum, tri-n-propoxyaluminum, tri-iso-butylaluminum, tri-sec-butylaluminum, tri-tert-butylaluminum, tri-iso-butoxyaluminum, tri-sec-butoxyaluminum, tri-tert-butoxyaluminum, triphenylaluminum, and tri-phenoxyaluminum.

[0022.] An aluminum phosphonate catalyst according to the present invention, bis(diisobutylaluminum)methylphosphonate, is synthesized as follows. A solution of 6.25 g of methylphosphonic acid in 125 ml of dry tetrahydrofuran is dissolved in a 250 ml erlenmeyer flask at approximately 25°C with magnetic stirring. Using a glass syringe, 100 ml of triisobutylaluminum, 25% weight solution in toluene, is transferred into a 500 ml 3-neck round bottomed flask swept with nitrogen. The flask also includes a thermometer, magnetic stir bar and a 250 ml addition funnel. The triisobutylaluminum solution is cooled to 0°C using a sodium chloride and ice water bath. The flask is swept with nitrogen throughout the setup procedure. The methylphosphonic acid solution is added to the addition funnel and then is added dropwise to the triisobutylaluminum solution under a nitrogen blanket at 0°C. The resulting solution is a clear, colorless, homogeneous solution and there is very little exothermic reaction. After all of the methylphosphonic acid has been added the reaction mixture is slowly warmed to approximately 25°C and held there for 1 hour with stirring. After 1 hour the stirring is stopped and the mixture is maintained under a nitrogen blanket for approximately 12 hours. Then the nitrogen is stopped and the volatiles are removed by vacuum stripping for 3 hours at 25°C. After the vacuum stripping is completed the vacuum is relieved and 75 g of toluene is added. The toluene solution is stirred for 1 hour and the resulting clear, colorless, homogeneous solution is used as detailed below. This synthetic pathway is

similar to that reported in the article by Mark R. Mason et al. entitled "Alkylaluminumphosphonate-catalyzed ring-opening homopolymerization of epichlorohydrin and propylene oxide", Journal of Organometallic Chemistry 2000, 599, 200-207, herein incorporated by reference.

[0023.] The formation of polyols for use in polyurethane systems utilizing a polyoxyalkylation of an initiator molecule by alkylene oxides is well known in the art. The present aluminum phosphonate catalysts can be used as replacements for base catalysts in substantially all processes used for the base catalysts with few, if any, changes to the procedure. As non-limiting examples, aluminum phosphonate catalysts can be used to make homogeneous polyoxyalkylation products, i.e. homopolymers; heterogeneous polyoxyalkylation products, i.e. heteric polyether polyols, various copolymers, including polymers having sections of different composition, e.g. block copolymers.

[0024.] Unlike base catalysts, the present aluminum phosphonate catalysts are water sensitive. Preferably water levels of all components used in polyol formation reactions are at or below 0.1 weight percent of the particular component, most preferably at or below 0.05 weight percent. It will be understood that any minor changes required for optimization of a process using an aluminum phosphonate catalyst, e.g. adjusting water levels or amounts of components, would be well within the ability of one of ordinary skill in the art and would not require extensive experimentation.

[0025.] Initiator molecules suitable for the present invention include all initiators having at least one alkylene oxide reactive hydrogen such as alcohols, polyhydric alcohols and amine compounds. Examples of alcohols include aliphatic and aromatic alcohols, such as lauryl alcohol, nonylphenol, octylphenol and C12 to C18 fatty alcohols. Examples of the polyhydric alcohols include diols, triols, and higher functional alcohols such as sucrose, and sorbitol. Amine compounds include the diamines such as ethylene diamine, toluene diamine, and other polyamines. In a preferred embodiment these initiator compounds are utilized to form oligomers having number average molecular weights of from about 200 to 1500. These oligomers can be formed utilizing known methods, e.g. self-catalyzing initiators or base catalysts, to add a plurality of alkylene oxides to the initiator molecules in a pre-reaction step. The oligomer molecules can then be utilized with the aluminum phosphonate catalysts of the present invention.

[0026.] The aluminum phosphonate catalysts of the present invention can also be used to modify polyols of a variety of sizes. This modification can take the form of capping an existing polyol with ethylene oxide, propylene oxide, butylene oxide, epichlorohydrin, or mixtures of these and other alkylene oxides. The polyols can be prepared using any of the known catalysts and may range in size from a number average molecular weight of 200 to 10,000 Daltons. An example of this modification process is described below in example 5. As used in the present specification and claims, the term initiator molecule is intended to encompass the short typical initiator molecules, oligomers and polyols to be modified as described in this specification.

[0027.] Specific examples of the utilization of the aluminum phosphonate catalysts of the present invention are described in detail below. The general procedure comprises reacting the initiator molecule with at least one alkylene oxide or a mixture of alkylene oxides in the presence of the aluminum phosphonate catalysts. Typical alkylene oxides include ethylene oxide, propylene oxide, butylene oxide, and epichlorohydrin. The initiator molecule and the alkylene oxide or oxides are reacted for periods of from 15 minutes to 15 hours. The reaction is generally conducted at a temperature of from 95° C to 150° C, and most preferably at a temperature between 105° C to 130° C. Oxyalkylation reactions conducted according to the present invention will result in the formation of polyols having unsaturation levels of less than 0.015 meq/g KOH. Most preferably, the procedure is utilized to produce polyols having unsaturation levels of less than 0.010 meq/g KOH.

[0028.] Generally, the aluminum phosphonate catalysts are utilized at levels of from 0.1 to 5.0 weight percent based on the total weight of the final product, most preferably at levels of from 0.1 to 0.5 weight percent. One notable difference between the aluminum phosphonate catalysts of the present invention and the DMC catalysts is that the aluminum phosphonate catalysts do not exhibit any reaction lag time during the oxyalkylation reaction. Another difference is the absence of formation of the so-called high molecular weight tail found in polyols produced using DMC catalysts. Once formed, polyols of the present invention can be utilized in any of the polyurethane procedures including formation of foams, coatings, adhesives, sealants, elastomers, and polymer polyols, such as graft polyols.

[0029.] It is not necessary to remove the catalysts of the present invention after formation of the polyols prior to their utilization in polyurethane systems. In some embodiments it can

be desirable, however, to remove the aluminum phosphonate catalysts prior to further utilization of the polyols. Any of the standard methods known in the art for removal of base catalysts or DMC catalysts can be utilized. One preferred method of removal of the aluminum phosphonate catalysts is through the use of binders for the aluminum such as magnesium silicate powders. One such example is Magnesol®, this compound includes acidic sites that bind the aluminum. The bound aluminum can then be filtered from the polyol prior to use of the polyols. Polyols of the invention may include amounts of aluminum phosphonate catalyst or residues thereof ranging from about 0.05 to about 5.0 weight percent of the final polyol based upon the amount of catalyst utilized and any processing of the polyol to remove the aluminum phosphonate catalyst.

[0030.] One advantage of the aluminum phosphonate catalysts of the present invention is that because they are capable of producing polyols having such low unsaturation levels of, for example, less than 0.008 meq/g KOH, one can produce high functionality polyols. For example, it is possible using a triol initiator to produce a 6000 molecular weight triol having a 10 to 20 percent ethylene oxide cap with a functionality of 2.9. As would be understood by one of ordinary skill in the art, as the size of the polyol increases, the amount of unsaturation naturally increases, so what is considered very low unsaturation may be higher as the polyol size increases.

[0031.] The present invention provides polyurethane products, such as flexible foams, rigid foams, coatings, adhesives, sealants, elastomers and thermoplastics which are the reaction products of polyols made using aluminum phosphonate catalysts, which polyols have very low unsaturation when compared to the same size polyol made using base catalysts and lack the high molecular weight tail as found in polyols made using DMC catalysts. The combination of these polyol features improves the quality of the polyurethane foams produced using the polyols. Low unsaturation provides a more uniform product since low unsaturation frees reactive sites. The high molecular weight tail of polyols made using DMC catalysts is recognized in the art as interfering with good quality foam production, thus the absence of the tail in low unsaturation polyols of the invention contributes to higher quality polyurethane.

[0032.] The production of flexible polyurethane foams by reacting polyisocyanates, for example aromatic diisocyanates, with compounds which are reactive toward isocyanates, for example polyether polyols, hereinafter also referred to generally as

polyetherols, and, if desired, chain extenders and/or cross-linkers in the presence of catalysts, blowing agents and, if desired, flame retardants, auxiliaries and/or additives is generally known. See U.S. Patent Nos. 4,554,295; 4,810,729;

5 5,830,926; and 6,228,899 incorporated herein by reference. An overview of polyols, their preparation, properties and applications in polyurethane chemistry is given in, for example, "Kunststoff-Handbuch", Volume 7, Polyurethane, 3rd edition, 1993, edited by G. Oertel, Carl Hanser Verlag, Munich.

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[0033.] To produce the flexible polyurethane foams of the invention, the organic, modified or unmodified polyisocyanates are reacted with the isocyanate-reactive compounds comprising the polyether polyols of the present invention in the presence of
15 blowing agents, catalysts and, if desired, flame retardants, auxiliaries and/or additives at from 0 to 100.degree. C., preferably from 15 to 80.degree. C., in such ratios that from 0.5 to 2, preferably from 0.8 to 1.3 and in particular about one reactive hydrogen atom(s) is/are present in bound form on the compounds
20 which are reactive toward isocyanates per NCO group and, if water is used as blowing agent, the molar ratio of equivalents of water to equivalents of NCO groups is 0.5-5:1, preferably 0.7-0.95:1 and in particular 0.75-0.85:1.

25 [0034.] The flexible PU foams are advantageously produced by the one-shot process by mixing two components A and B. In this method, the compounds which are reactive toward isocyanates, the flame retardants, the blowing agents, the catalysts and, if used, the auxiliaries and/or additives are combined to form the A components and the polyisocyanates, if desired in admixture with
30 flame retardants, auxiliaries and/or additives and inert, physically acting blowing agents are used as component B. Thus, the A and B components only have to be intensively mixed before production of the flexible polyurethane foams. The reaction mixtures
35 can be foamed in open or closed molds and also to give block foam.

[0035.] The production of rigid polyurethane foams based on isocyanate is well known in the art and comprises mixing two components A and B. Typically, the compounds which are reactive toward isocyanates, the flame retardants, the blowing agents, the catalysts and, if used, the auxiliaries and/or additives are combined to form the A components and the polyisocyanates, if desired in admixture with flame retardants, auxiliaries and/or
45 additives and inert, physically acting blowing agents are used as component B.. The various permutations of methods for the preparation of polyurethane-containing foams are well known. For a

reference to said methods and to various catalysts, blowing agents, surfactants, other additives, and polyisocyanates, see U.S. Pat. No. 4,209,609 and the references cited therein; said references and the teachings of U.S. Pat. No. 4,209,609 are
5 hereby incorporated herein by reference.

[0036.] Important chemical starting materials for rigid foams are polyfunctional isocyanates. Chemical structures formed from the polyisocyanates can be polyurethanes, polyureas, polyisocyanurates and also further isocyanate adducts. The type of these
10 structures is controlled by the reaction partners of the isocyanates, the catalysis and the reaction conditions. The production of such foams is described, for example, in U.S. Patent No. 6,284,812, incorporated herein by reference, and in the Kunststoff-Handbuch, Volume VII "polyurethane", 3rd Edition, edited by
15 Gunter Oertel, Carl-Hanser-Verlag, Munich, Vienna, 1993.

[0037.] Rigid polyurethane foams typically can be distinguished from flexible foams by the presence of higher levels of
20 isocyanurate in the rigid foam. In addition, flexible foam typically uses polymer polyol as part of the overall polyol content in the foam composition, along with conventional triols of 4000-5000 weight average molecular weight (Mw) and hydroxyl number (OH #) of 28-35. Rigid polyurethane foam compositions
25 typically use 500-1000 Mw polyols with OH # of 160-700. Rigid foam can also be differentiated from flexible foam by the isocyanate (NCO) index of the foam composition. Rigid foam compositions typically use a 100-300 NCO index whereas flexible foam compositions typically use a 70-115 NCO index.

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[0038.] Polyols known and customary for producing rigid foams are, for example polyether polyols with 2-8 hydroxyl groups, preferably having a functionality of at least 3, most preferably at least 3.5, and a hydroxyl number of greater than 100 mg KOH/g, in
35 particular greater than 300 mg KOH/g, able to be prepared by addition of ethylene oxide and/or, in particular, propylene oxide onto at least 3-functional initiator substances, for example aromatic amines such as tolylenediamine or diphenylmethanediamine, or polyfunctional hydroxyl-containing compounds such as sorbitol,
40 sucrose, mannitol, lignin, condensates of phenol and formaldehyde.

[0039.] For rigid foams, the polyol component also includes chain extenders and/or crosslinkers. Chain extenders used are
45 bifunctional, low molecular weight alcohols, in particular those having a molecular weight of up to 400, for example ethylene glycol, propylene glycol, butanediol, hexanediol. Crosslinkers

used are at least trifunctional, low molecular weight alcohols, for example glycerol, trimethylolpropane, pentaerythritol, sucrose or sorbitol. As polyisocyanates a), use is made of the customary and known aliphatic and in particular aromatic polyiso-
5 cyanates.

[0040.] Methods of preparing coatings, adhesives, sealants and elastomers (CASE materials) by reacting polyisocyanates, for example aromatic diisocyanates, with compounds which are reactive
10 toward isocyanates, for example polyether polyols, hereinafter also referred to generally as polyetherols, and, if desired, chain extenders and/or crosslinkers in the presence of catalysts, and, if desired, blowing agents flame retardants, auxiliaries and/or additives is generally known. For a reference to said
15 methods and to various polyols, cross-linkers, chain extenders, catalysts, blowing agents, surfactants, other additives, and polyisocyanates, see U.S. Pat. Nos. 6,100,363; 6,103,850; 6,197,839; and 6,310,114, as well as the references cited therein; said references and the teachings of said patents are
20 hereby incorporated herein by reference.

[0041.] Typical coatings, adhesives, sealants and elastomers are based upon polyols having diols and/or triols for initiators and the isocyanates used are polyisocyanates, preferably aromatic
25 diisocyanates. To obtain different properties desirable in each of coatings, adhesives, sealants and elastomers, the molecular weight of the isocyanate reactive component, e.g. the polyether polyol, is varied wherein typically a higher molecular weight polyetherol is desirable to increase flexibility, while increased
30 functionality of the polyol is desirable for improved abrasion resistance and rigidity.

[0042.] Elastomeric polyurethane polymers have heretofore been used in the art for compounding sealants or adhesives for bonding
35 or adhering a variety of materials. Such polyurethane polymers are often prepared to have terminal isocyanate groups. On exposure to atmospheric moisture, the isocyanate groups react with water to form amino groups with the evolution of carbon dioxide. The amino groups so formed further react with available iso-
40 cyanate groups to form urea linkages, thus effecting a cure of the polymer in the sealant and binding the materials to be adhered.

[0043.] In general, an elastomer is prepared by reacting a
45 polyoxyalkylene polyether polyol with an organic isocyanate in the presence of a chain extender. The chain extender may be a diol or a mixture of triols and diols such that the overall func-

tionality of the mixture is generally less than 2.3. The polyoxyalkylene polyether polyols used in the preparation of elastomers generally have molecular weights ranging from 2,000 to 5,000. For the preparation of sealants, the chain extender may
5 be a triol or a mixture of diols, triols, and/or tetrols, such that the overall functionality of the mixture ranges from greater than 2.3 to 3.0.

[0044.] Thermoplastic polyurethanes can be prepared by known
10 methods from isocyanates, compounds which are reactive toward isocyanates and, if desired chain extenders in the presence or absence of catalysts and/or auxiliaries and/or additives, where the ratio of the isocyanate groups of the isocyanate component to the sum of isocyanate-reactive groups of the components compounds
15 reactive toward isocyanates and, if used, chain extenders is usually from 1:0.9 to 1:1.1. See for example, U.S. Patent Nos. 6,165,399 and 6,319,985 which are incorporated herein by reference.

20 [0045.] Suitable organic isocyanates are preferably aliphatic, cycloaliphatic and in particular aromatic diisocyanates. Suitable substances which are reactive toward isocyanates are, for example, polyhydroxyl compounds having molecular weights of from 500 to 8000, preferably polyetherols and polyesterols. The
25 polyhydroxyl compounds mentioned can be used as individual components or in the form of mixtures.

[0046.] The mixtures for preparing the TPU are usually based at least predominantly on bifunctional isocyanate-reactive
30 substances, i.e. the mean functionality of the isocyanate reactive component is preferably from 1.8 to 2.6, particularly preferably from 1.9 to 2.2. The TPUs are thus predominantly unbranched, i.e. predominantly uncrosslinked. To set hardness and melting points of TPUs, the molar ratio of the formative components, that is the isocyanate reactive component and chain
35 extenders is usually varied in a range from 1: 0.8 to 1:10, with the hardness and the melting point of the TPUs increasing with increasing diol content.

40 [0047.] For TPU formation, preference is given to using polyetherols derived from 1,2-propylene oxide and ethylene oxide in which more than 50%, preferably from 60 to 80%, of the OH groups are primary hydroxyl groups and in which at least part of the ethylene oxide is arranged as a terminal block. The poly-
45 etherols, which are essentially linear in the case of the TPUs, have molecular weights of from 500 to 8000, preferably from 600

to 6000 and in particular from 800 to 3500. They can be used either individually or in the form of mixtures with one another.

[0048.] Quasi-prepolymers may also be made using polyols made using aluminum phosphonate catalysts and employed in making the polyurethanes of the subject invention. These quasi-prepolymers are prepared by reacting an excess of organic polyisocyanate or mixtures thereof with an active hydrogen-containing compound determined by the well-known Zerewitinoff Test, as described by Kohler in Journal of the American Chemical Society, 49, 3181 (1927). These compounds and their methods of preparation are well known in the art. The use of any one specific active hydrogen compound is not critical hereto; rather, any such compound can be employed herein. Generally, the quasi-prepolymers have a free isocyanate content of from 15 percent to 40 percent by weight.

[0049.] Having thus described the invention, the following examples are given by way of illustration.

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EXAMPLE 1: Oxypropylenation of a diol initiator molecule

[0050.] A 1 gallon nitrogen flushed autoclave is charged with 400 g of a polypropylene glycol having a number average molecular weight of 700 and 100 g of a 25% by weight solution of bis(diisobutylaluminum)methylphosphonate in toluene and tetrahydrofuran, with agitation. The solvent is removed by batch vacuum stripping at 110°C for 0.5 hours. Then 1886 g of propylene oxide is fed into the autoclave at a rate of approximately 300 g/hour, at 110°C and a pressure of less than 90 psig. The contents are reacted to constant pressure at 110°C for approximately 5 hours. The autoclave is then evacuated to less than 10 mm Hg for 60 minutes. The vacuum is then relieved. The produced polyetherol is a clear fluid having a number average molecular weight of 4655, a hydroxyl number of 24.1 meq/g KOH and an unsaturation of 0.005 meq/g KOH.

EXAMPLE 2: Oxypropylenation of a triol initiator molecule

[0051.] A 5 gallon nitrogen flushed autoclave is charged with 1900 g of a glycerin propylene oxide adduct oligomer having a number average molecular weight of 700 and 220 g of a 25% by weight solution of bis(di-sec-butoxyaluminum)phenylphosphonate in toluene and tetrahydrofuran, with agitation. The solvent is removed by batch vacuum stripping at 110°C for 0.5 hours. Then 14100 g of propylene oxide is fed into the autoclave at a rate of approximately 1000 g/hour, at 110°C and a pressure of less than

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90 psig. The rate of propylene oxide addition is adjusted as needed to maintain the concentration of unreacted propylene oxide at or below 8%. The contents are reacted to constant pressure at 110°C for approximately 5 hours. The autoclave is then evacuated to less than 10 mm Hg for 60 minutes. The vacuum is then relieved with nitrogen, the contents cooled to 105°C and transferred to a standard filter mix tank for removal of the catalyst. The contents are treated with 500 g of Magnesol® and 120 g of water for 1 hour at 105°C. The treated contents are recycled through the filter element until the filtrate is haze free indicating full removal of the particulate Magnesol® with bound catalyst. These filtration procedures are well known in the art and can comprise use of systems as simple as Buchner funnels with medium weight filter paper designed to remove particles in the size range of greater than 50 to 100 microns. The filtrate was then heated to 105°C and vacuum stripped at less than 10 mm Hg for 1 hour. After 1 hour the vacuum is relieved with nitrogen. The clear fluid polyetherol has a number average molecular weight of 5744, a hydroxyl number of 29.3 meq/g KOH and an unsaturation of 0.008 meq/g KOH.

EXAMPLE 3: Oxyalkylenation of a triol initiator molecule

[0052.] A 5 gallon nitrogen flushed autoclave is charged with 3528 g of a glycerin propylene oxide adduct oligomer having a number average molecular weight of 700 and 250 g of a 25% by weight solution of bis(diisobutylaluminum)methylphosphonate in toluene and tetrahydrofuran, with agitation. The solvent is removed by batch vacuum stripping at 110°C for 0.5 hours. Then a mixture of 8304 g of propylene oxide and 2010 g of ethylene oxide is fed into the autoclave at a rate of approximately 1000 g/hour, at 110°C and a pressure of less than 90 psig. The contents are reacted to constant pressure at 110°C for approximately 3 hours. The autoclave is then vented to 34 psig and 1780 g of propylene oxide is fed at a rate of 2000 g/hour into the autoclave at 110°C and a pressure of less than 90 psig. The contents are reacted to constant pressure at 110°C for no more than 5 hours. The autoclave is then evacuated to less than 10 mm Hg for 60 minutes. Then the vacuum is relieved with nitrogen and the polyol recovered. The clear fluid polyetherol has a number average molecular weight of 2100, a hydroxyl number of 69.8 meq/g KOH and an unsaturation of 0.019 meq/g KOH.

EXAMPLE 4: Oxyalkylenation of a triol initiator molecule

[0053.] A 1 gallon nitrogen flushed autoclave is charged with 700 g of a glycerin propylene oxide adduct oligomer having a number average molecular weight of 700 and 100 g of a 25% by weight solution of bis(diisobutylaluminum)phenylphosphonate in toluene and tetrahydrofuran, with agitation. The solvent is removed by batch vacuum stripping at 110°C for 0.5 hours. Then 2020 g of propylene oxide is fed into the autoclave at a rate of approximately 1000 g/hour, at 110°C and a pressure of less than 90 psig. The contents are reacted to constant pressure at 110°C for approximately 3 hours. The autoclave is then vented to 34 psig and 415 g of ethylene oxide is fed at a rate of 400 g/hour at 110°C and a pressure of less than 90 psig. The contents are reacted to constant pressure at 110°C for approximately 3 hours. The autoclave is then evacuated to less than 10 mm Hg for 60 minutes. Then the vacuum is relieved with nitrogen and the polyol recovered. The clear fluid polyetherol has a number average molecular weight of 3255, a hydroxyl number of 51.7 meq/g KOH and an unsaturation of 0.011 meq/g KOH.

EXAMPLE 5: Terminal capping with ethylene oxide of a triol oligomer

[0054.] A 1 gallon nitrogen flushed autoclave is charged with 2000 g of a glycerin propylene oxide adduct oligomer having a number average molecular weight of 3200 and 25 g of an approximately 40% by weight solution of bis(di-sec-butoxyaluminum)phenylphosphonate in toluene and tetrahydrofuran, with agitation. The solvent is removed by batch vacuum stripping at 125°C for 0.5 hours. Then 360 g of ethylene oxide is fed into the autoclave at a rate of approximately 600 g/hour, at 130°C and a pressure of less than 90 psig. The contents are reacted to constant pressure at 130°C for approximately 1 hour. The autoclave is then evacuated to less than 10 mm Hg for 60 minutes. Then the contents are cooled to 80°C, the vacuum is relieved with nitrogen and the polyol is recovered. The clear fluid polyetherol has a number average molecular weight of 4906 and a hydroxyl number of 34.3 meq/g KOH, indicating addition of approximately 38 ethylene oxides per oligomer.

EXAMPLE 6: Comparison of KOH catalyzed polyols with Aluminum phosphonate catalyzed polyols

[0055.] A series of different sized polyols are prepared using a triol initiator and KOH catalyst. Using the same initiator a similar sized series of polyols are prepared according to Example 2. The results are presented in Table 1 below.

Table 1

	Catalyst used to form polyol	Number av- erage mo- lecular weight	Hydroxyl number, meq/g KOH	Unsaturation, meq/g KOH	Actual functional- ity
5	KOH	3,366	50.0	0.028	2.81
	KOH	4,808	35.0	0.050	2.57
10	KOH	6,327	26.6	0.090	2.17
	Aluminum phosphonate	2,805	60.0	0.007	2.96
	Aluminum phosphonate	5,884	28.6	0.007	2.92
15	Aluminum phosphonate	6,983	24.1	0.005	2.94

[0056.] The results demonstrate the extraordinary value of the present catalysts. The polyols produced using the aluminum phosphonate catalysts have a much higher functionality and much lower unsaturation level for a similar size polyol. The aluminum phosphonate catalysts can be used to provide terminal capping of polyols with an alkylene oxide. The suitable alkylene oxides include ethylene oxide, propylene oxide, butylene oxide and epichlorohydrin among others. When capping with the ethylene oxide the amount of terminal cap preferably ranges from 5 to 80% by weight based on the total weight of the polyetherol, and more preferably 5 to 20 % by weight. When capping with propylene oxide the amount of terminal cap preferably ranges from 5 to 80% by weight based on the total weight of the polyetherol, and more preferably 5 to 15 % by weight.

EXAMPLE 7: Comparative formation of foams

[0057.] The procedure of Example 2 is used to form a triol polyol based on an initiator mixture of glycerin and a small amount of dipropylene glycol according to the procedure of the present invention, the triol is designated polyol A. Polyol A has a number average molecular weight of 2486, a hydroxyl number of 60.4 meq/g KOH, and an unsaturation of 0.011 meq/g KOH. The aluminum phosphonate catalyst is not removed from polyol A. Using the same initiator mixture a similar sized polyol, designated polyol B, is formed according to conventional procedures using KOH as the catalyst. The produced polyol has a number average molecular weight of 2600, a hydroxyl number of 57.6 meq/g KOH, and an unsaturation of 0.032 meq/g KOH. The KOH catalyst is

removed from polyol B. Each polyol is then used to form a polyurethane foam. The foams are prepared using conventional procedures and the components listed in Table 2 below. The amount of tin catalyst is slightly increased in Foam A because of the acidity of the residual phosphonate.

Table 2

Component	Foam A, amount in grams	Foam B, amount in grams
Polyol A	400.00	0.00
Polyol B	0.00	400.00
Dabco® 33-LV amine	0.25	0.25
BF-2370 surfactant	1.00	1.00
Water	4.00	4.00
T-10 tin catalyst	0.60	0.45
Toluene diisocyanate	212.20	210.30

[0058.] The foams A and B were then tested for airflow, hardness, tear, elongation, and compression set. The results are presented below in Table 3. All parameters were tested according to ASTM method D 3574 except for the compression set wet method. The compression set wet method used is the same as JIS K-6400, Japanese Industry Standards. The method will be included as test L of ASTM method D 3574 in 2002. Briefly, the method is exposure at 50°C, 95 % relative humidity for 22 hours followed by a 30-minute recovery period.

Table 3

Foam	Air flow, Cubic feet/minute	Hardness, lbs./foot	Tear, PPI	Break Elongation, heat aged, %	Compression set wet, %
Foam A	4.67	70.48	1.60	136.62	3.41
Foam B	3.88	74.64	1.75	129.34	3.09

[0059.] The results demonstrate that foam A produced using polyol A, prepared according to the present invention, has very similar to even better properties when compared to foam B prepared from polyol B, a KOH catalyzed polyol. Furthermore polyol A, produced according to the present invention, has the additional advantages of a much lower unsaturation and no need to remove the catalyst prior to preparation of the foam.

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[0060.] The foregoing invention has been described in accordance with the relevant legal standards, thus the description is exemplary rather than limiting in nature. Variations and modifications to the disclosed embodiment may become apparent to those skilled in the art and do come within the scope of the invention. Accordingly, the scope of legal protection afforded this invention can only be determined by studying the following claims.

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CLAIMS

1. A composition of matter comprising:
- 5 a) a polyurethane material and
b) aluminum phosphonate catalyst having the general structure of $\text{RPO}-(\text{OAlR}'\text{R}'')_2$ or residues of said aluminum phosphonate catalyst, wherein:
- 10 P represents pentavalent phosphorous;
O represents oxygen;
Al represents aluminum
R comprises a hydrogen, an alkyl group, or an aryl group; and
15 R' and R'' independently comprise a halide, an alkyl group, an alkoxy group, an aryl group, or an aryloxy group, and/or residues of said aluminum phosphonate.
2. The composition of matter as recited in Claim 1 wherein:
20 R is a methyl group; and
R' and R'' independently comprise one of an ethyl group, an ethoxy group, a propyl group, a propoxy group, a butyl group, a butoxy group, a phenyl group, or a phenoxy group.
- 25 3. The composition of matter as recited in Claim 1, wherein said aluminum phosphonate is present at levels of from approximately 0.001 to 5.0 weight percent based on the total weight of the polyurethane.
- 30 4. The composition of matter of Claim 1, wherein the polyurethane material is selected from the group consisting of flexible foams, rigid foams, coatings, adhesives, sealants, elastomers and thermoplastics.
- 35 5. A polyurethane product comprising greater than 0.001 weight percent of aluminum phosphonate catalyst and/or aluminum phosphonate catalyst residues based on the total weight of the polyurethane product, said aluminum phosphonate catalyst having the general structure of $\text{RPO}-(\text{OAlR}'\text{R}'')_2$ wherein: O
40 represents oxygen; P represents pentavalent phosphorous; Al represents aluminum; R comprises a hydrogen, an alkyl group, or an aryl group; and R' and R'' independently comprise a halide, an alkyl group, an alkoxy group, an aryl group, or an aryloxy group.
- 45 6. The polyurethane product of claim 5 wherein:

R is a methyl group; and

R' and R" independently comprise one of an ethyl group, an ethoxy group, a propyl group, a propoxy group, a butyl group, a butoxy group, a phenyl group, or a phenoxy group.

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7. The polyurethane product of Claim 5, wherein the product is selected from the group consisting of flexible foams, rigid foams, coatings, adhesives, sealants, elastomers and thermoplastics.

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8. A polyurethane product formed according to a process comprising the steps of:

- a) providing at least one alkylene oxide;
- 15 b) providing at least one initiator molecule having at least one alkylene oxide reactive hydrogen;
- c) providing an aluminum phosphonate catalyst having the general structure of $\text{RPO}-(\text{OAlR}'\text{R}'')_2$ wherein: O represents oxygen; P represents pentavalent phosphorous; Al represents aluminum; R comprises a hydrogen, an alkyl
- 20 group, or an aryl group; and R' and R" independently comprise a halide, an alkyl group, an alkoxy group, an aryl group, or an aryloxy group;
- d) reacting the at least one alkylene oxide with the at
- 25 least one initiator molecule in the presence of an aluminum phosphonate catalyst to form a polyether polyol D) having reactive hydrogens;
- e) providing at least one organic polyisocyanate and/or isocyanate pre-polymer E) having functional groups reactive
- 30 toward said polyether polyol reactive hydrogens;
- f) reacting E) with D), and optionally, with additional substances having reactive hydrogens, in the presence of
- g) a urethane promoting catalyst; and
- h) optionally, blowing agents, cross-linkers, surfactants,
- 35 fillers, pigments, antioxidants and stabilizers.

9. The polyurethane product of Claim 8, wherein step c) comprises providing the aluminum phosphonate catalyst in an amount of from 0.1 to 5.0 weight percent based on the total
- 40 weight of the polyether polyol.

10. The polyurethane product of Claim 8, comprising providing as the aluminum phosphonate catalyst an aluminum phosphonate wherein: R is a methyl group; and R' and R" independently
- 45 comprise one of an ethyl group, an ethoxy group, a propyl

group, a propoxy group, a butyl group, a butoxy group, a phenyl group, or a phenoxy group.

11. The polyurethane product of Claim 8, wherein the product is
5 selected from the group consisting of flexible foams, rigid foams, coatings, adhesives, sealants, elastomers and thermoplastics.
12. A method of producing a polyurethane product comprising re-
10 acting:
 - a) a polyol component comprising at least one polyoxy-
alkylene polyether polyol produced in the presence of an
aluminum phosphonate catalyst, and having an average
15 equivalent weight of from about 100 to about 10,000, and
 - b) an organic isocyanate
 - c) in the presence of
 - d) if desired, a catalyst, a blowing agent, and
 - e) optionally, cross-linkers, surfactants, flame retardants,
20 fillers, pigments, antioxidants and stabilizers.
13. A method as recited in claim 12 wherein said polyether polyol
comprises a styrene acrylonitrile graft polymer polyol dis-
25 persion and the foam comprises a flexible foam.
14. A method as recited in claim 12 wherein said polyol comprises
a mixture of at least one conventional polyether polyol and
at least one graft polymer polyol dispersion and the foam
30 comprises a flexible foam.
15. A flexible polyurethane foam made according to the process as
recited in claim 12.
16. A rigid polyurethane foam made according to the process as
35 recited in claim 12.
17. A thermoplastic polyurethane made according to the process as
recited in claim 12.
18. A polyurethane coating made according to the process as re-
40 cited in claim 12.
19. A polyurethane adhesive made according to the process as re-
cited in claim 12.
- 45 20. A polyurethane sealant made according to the process as re-
cited in claim 12.

21. A polyurethane elastomer made according to the process as re-
cited in claim 12.
22. A polyurethane elastomer comprising a reaction product of an
organic polyisocyanate with a polyol component comprising at
least one polyether polyol having an equivalent weight of at
least 900 and comprising a reaction product of propylene
oxide and a di-hydroxyl functionality initiator molecule in
the presence of an aluminum phosphonate catalyst.
23. A method of producing a polyurethane elastomer comprising re-
acting:
- a) a polyol component comprising at least one polyoxy-
alkylene polyether polyol produced in the presence of an
aluminum phosphonate catalyst, and
 - b) an organic isocyanate
 - c) in the presence of
 - d) if desired, one or more chain extenders, and
 - e) optionally a catalyst, a surfactant, a blowing agent, and
an effective amount of an flame retardant
 - f) where the overall functionality of the polyol component
(a) and the chain extenders (c) is less than 2.3.
24. A polyurethane elastomer made according to the process as re-
cited in claim 23.
25. A method of producing a polyurethane adhesive comprising re-
acting:
- a) a polyol component comprising at least one polyoxy-
alkylene polyether polyol produced in the presence of an
aluminum phosphonate catalyst, and
 - b) an excess of organic isocyanate
 - c) in the presence of
 - d) if desired, one or more chain extenders, and
 - e) optionally a catalyst, a surfactant, a blowing agent, and
an effective amount of an flame retardant.
26. A polyurethane adhesive made according to the process as re-
cited in claim 25.
27. A method of producing a polyurethane sealant comprising re-
acting:

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- 5 a) a polyol component comprising at least one polyoxy-alkylene polyether polyol produced in the presence of an aluminum phosphonate catalyst, and
b) an organic isocyanate
c) in the presence of
d) if desired, one or more chain extenders, and
e) optionally a catalyst, a surfactant, a blowing agent, and an effective amount of an flame retardant

10 where the overall functionality of the polyol component (a) and the chain extenders (c) is greater than 2.3 to 3.0.

28. A polyurethane sealant made according to the process as recited in claim 27.

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29. A method of producing a thermoplastic polyurethane article comprising reacting:

- 20 a) compounds which are reactive toward isocyanates which comprise a polyol component comprising at least one polyoxyalkylene polyether polyol produced in the presence of an aluminum phosphonate catalyst, said polyol component having an average molecular weight of from 500 to 8000, and
25 b) an organic isocyanate
c) in the presence of
d) if desired, a catalyst, a blowing agent, and
e) optionally a surfactant, a chain extender, and an effective amount of an flame retardant;

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where the ratio of the isocyanate groups of the component (b) to the sum of isocyanate-reactive groups of the components (a) and, if used, said chain extender is from approximately 1:0.9 to 1:1.1.

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30. A thermoplastic polyurethane made according to the process as recited in claim 29.

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