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POLYMER-CLAY NANOCOMPOSITE METHOD

STATEMENT OF GOVERNMENT INTEREST

[0001] The invention described herein may be manufactured and used by or for the Government of the United States of America for governmental purposes without the payment of any royalties thereon or therefor.

CROSS REFERENCE TO OTHER PATENT APPLICATIONS

[0002] None.

BACKGROUND OF THE INVENTION

1) FIELD OF THE INVENTION

[0003] The present invention relates generally to barrier coatings technology. More particularly, this invention pertains to materials and methods for impeding diffusion of penetrant molecules through a barrier coating.

2) DESCRIPTION OF THE RELATED ART

[0004] The permeation of molecules (e.g., water, oil, plasticizer) through polymers has led to reduced performance and even failures in a variety of products designed for employment in a marine environment. Consequently, improved designs for coatings, cable jackets, and component hoses that prevent, or at least substantially impede, diffusion by penetrant molecules (e.g., water, petroleum distillates, and/or fill fluid) are a

recurring need in the field. However, techniques introduced for combating penetrant permeation should not compromise certain desirable properties of barrier coatings and/or the products those coatings protect. For example, barrier coatings and/or the coated products may exhibit important acoustic, structural, and/or buoyancy properties that should not be hindered.

[0005] Certain known techniques for improving resistance to penetrant permeation often operate at the expense of maintaining desirable product properties. As an example, the thickness of a hose may be increased to create a longer path for penetrant molecules to traverse, thus making it more difficult for molecules to penetrate the hose. However, increasing thickness makes the hose heavier and less flexible.

[0006] As another example, a hose may be made with material with improved barrier properties (e.g., Polytetrafluoroethylene (PTFE), fluoroelastomer, or crystalline polymer). However, these materials typically fail to meet acoustic, structural, and/or buoyancy requirements.

[0007] As yet another example, a hose may be made with multiple layers of water-blocking material disposed between other materials that meet acoustic and structural requirements. However, manufacturing such a complex layered structure, as well as maintaining hoses so constructed, is typically difficult and expensive. Moreover, differences in the sound speed and density

of the different materials may impact acoustic requirements. Additionally, penetrant molecules may include polar (e.g., water) and non-polar (e.g., a petroleum distillate) molecules, and hose materials such as polymer are generally chemically resistant (i.e., have low permeability and solubility) to either polar molecules or non-polar molecules, but not both.

[0008] U.S. Patent No. 8,470,921 incorporates a castable polymer with clay particles about an acoustic device. The clay particles are phyllosilicates having a high aspect ratio that are pre-treated for compatibility with organic polymers. The acoustic device is provided in a mold and the castable polymer mixture is provided around the device. The polymer mixture is allowed to set, encapsulating the device in an ultra-low permeability thermoset polymer.

[0009] Accordingly, a need exists for a solution to at least one of the aforementioned challenges in penetrant permeation in connection with flexible extended components such as hoses and cable jackets. Thus, there is a need for improved barrier coating designs and manufacturing methods that may advantageously lead to increased reliability and effective service life in marine hardware systems.

SUMMARY OF THE INVENTION

[0010] With the above in mind, a need exists for a solution to at least one of the aforementioned challenges in combating penetrant permeation. For instance, a need exists for manufacturing products that can transport fluids using materials that resist penetration, while realizing advantages in economy of space, scalability, manufacturing cost, materials cost, and/or performance.

[0011] Accordingly, embodiments of the present invention are related to a barrier material that can be applied to improve the impermeability of products. The material includes nanoparticle platelets of clay that may be aligned to obstruct molecules. The material may be applied to the product via extrusion to align the platelets. In certain embodiments, the barrier material may be provided in the form of pellets that include the clay platelets. In this form, the material may be more readily utilized by extrusion systems.

[0012] In certain embodiments, a method of manufacturing an extruded product having a barrier coating may include receiving an extrusion material at an extrusion channel of an extrusion system. The extrusion channel may receive a barrier material, which may be disposed between the inner surface of the extrusion channel and the outer surface of the extrusion material. The barrier material comprises a polymer-clay nanocomposite, which

in turn may comprise clay platelets. The clay platelets are aligned by moving the extrusion material and the barrier material through the extrusion channel. This applies a shear force to the polymer-clay nanocomposite which acts to align the clay platelets. The extrusion material and the barrier material may be extruded to form the barrier coating on the outer surface of the extruded product.

[0013] Embodiments may include various features. Clay platelets can be aligned by moving the extrusion material and the barrier material through the extrusion channel. This may include pushing the extrusion material and the barrier material through the extrusion channel to apply a shear force. The shear force may result from a first force of friction from the inner surface of the extrusion channel and a second force of friction from the outer surface of the extrusion material that may be moving relative to the extrusion channel. The clay platelets can also be aligned by moving the extrusion material and the barrier material through the extrusion channel. This may include utilizing an extrusion ram to push the extrusion material and the barrier material through the extrusion channel. Extrusion material can be received into an extrusion channel of an extrusion system by utilizing an extrusion ram to push the extrusion material through the extrusion channel. Barrier material can be received through an additive feeder that may

intersect with the extrusion channel. The extrusion channel can be joined to a die or have different shapes for producing a flat product, a hose, or other known extrudate forms.

[0014] Various materials can be utilized. The extrusion material may include thermoplastic polyurethane. The polymer-clay nanocomposite may include a phyllosilicate mineral. The polymer-clay nanocomposite may be characterized by a clay-to-polymer weight percentage of less than 10%, such as in the range of 2% to 8%, inclusive of the endpoints of the range. The barrier material may comprise pellets that may include the polymer-clay nanocomposite.

[0015] In other embodiments, the extrusion system may comprise an extrusion channel with an elongate barrel having an axis that defines an extrusion direction. An additive feeder is coupled to the extrusion channel between ends of the extrusion channel. An extrusion ram is provided having a cross section with an outer border that matches the inner surface of the extrusion channel to allow the extrusion ram to traverse the extrusion channel.

[0016] In certain embodiments, a method of manufacturing a barrier material may include mixing a polymer and a plurality of clay particles. The polymer may comprise a thermoplastic polyurethane (TPU), and each clay particle may comprise clay platelets. The mixing of the polymer and the clay particles may

exfoliate the clay platelets to yield a polymer-clay nanocomposite. The polymer-clay nanocomposite may be pelletized to yield the barrier material that may comprise polymer-clay nanocomposite pellets. Each polymer-clay nanocomposite pellet may include exfoliated clay platelets.

[0017] These polymer-clay nanocomposite pellets can be made utilizing various methods. The clay particles can be pretreated prior to mixing the polymer and the clay particles to make the clay particles more compatible with the polymer. The pretreating may comprise converting hydrophilic surfaces of the clay platelets to organophilic surfaces. The pretreatment may include pretreating with an ion exchange reaction with an organic cation, an alkylammonium ion, and/or a silane ion. The clay particles may comprise a phyllosilicate mineral. Mixing the polymer and the clay particles may further include mixing the polymer and the clay particles at a clay-to-polymer weight percentage of less than 10%, such as in the range of 2% to 8%, inclusive of the endpoints of the range. The polymer-clay nanocomposite can be pelletized to yield the polymer-clay nanocomposite pellets where the longest diameter may be less than one inch.

[0018] In certain embodiments, a barrier material for forming a barrier coating on an extruded product may comprise a plurality of pellets. Each pellet may include a nanocomposite.

The nanocomposite may include a thermoplastic polyurethane (TPU) and clay platelets exfoliated within the thermoplastic polyurethane. The clay platelets may comprise a phyllosilicate mineral. The weight percentage of the clay particles to the thermoplastic polyurethane may be less than 10% (e.g., 2% to 8%, inclusive of the endpoints of the range). The clay platelets may be configured to assume an aligned state when extruded to form the barrier coating on the extruded product. Each pellet may have a size where a longest diameter may be less than one inch.

[0019] These and other objects, features, and advantages of the present invention will become more readily apparent from the attached drawings and the detailed description of the preferred embodiments, which follow.

BRIEF DESCRIPTION OF THE DRAWINGS

[0020] Embodiments of the invention will hereinafter be described in conjunction with the appended drawings provided to illustrate and not to limit the invention, where like designations denote like elements (e.g., like reference numerals refer to like parts throughout the several views of the drawings), and in which:

[0021] FIGS. 1A is a schematic diagram of clay particles with clay platelets in their natural state;

[0022] FIG. 1B is a schematic diagram of a penetrant traveling through natural clay particles;

[0023] FIG. 2 is a schematic diagram of clay platelets in an exfoliated state;

[0024] FIG. 3A is a schematic diagram of aligned, exfoliated clay platelets;

[0025] FIG. 3B is a schematic diagram of a penetrant traveling through aligned, exfoliated clay platelets;

[0026] FIG. 4 is a schematic diagram of an exemplary polymer-clay nanocomposite extrusion system;

[0027] FIG. 5 is a schematic diagram of a polymer-clay nanocomposite extrusion system for extruding a coating over an object;

[0028] FIG. 6 is a schematic diagram of a system for producing polymer-clay nanocomposite pellets;

[0029] FIG. 7 is a schematic diagram of a polymer-clay nanocomposite pellet system for extruding a coating over an object; and

[0030] FIG. 8 is a flow chart illustrating an exemplary method of manufacturing a polymer-clay nanocomposite material.

DETAILED DESCRIPTION OF THE INVENTION

[0031] The present invention will now be more fully described with reference to the accompanying drawings, in which

embodiments of the invention are shown. This invention may, however, be embodied in many different forms and should not be construed as limited to the embodiments set forth herein. Rather, these embodiments are provided so that this disclosure is thorough, complete, and fully conveys the scope of the invention to those skilled in the art.

[0032] Products may be made of certain product materials that have desirable qualities. For example, and without limitation, polymers may be optically or acoustically clear, meaning that optical or acoustic energy is able to enter and transit through the material with a minimal amount of reflection, loss, distortion, and/or absorption. However, these clear product materials may nonetheless exhibit undesirable permeability.

[0033] In certain embodiments, a barrier material may be applied to improve the impermeability of the product. The material may include nanoparticle platelets of clay that may be aligned such that platelet closeness and orientation may operate to obstruct diffusion of penetrant molecules between adjacent platelets. The barrier material may be applied to the product via extrusion, which may align the platelets. In certain embodiments, the barrier material may be provided in the form of pellets that may include the clay platelets.

[0034] FIGS. 1A through 3B include schematic diagrams that illustrate how clay platelets function as barriers to molecules.

Schematic diagrams in FIG. 1A and FIG. 1B illustrate an exemplary grouping of clay particles 14 with clay platelets 16 oriented in their natural state. As shown, the clay particles 14 in their natural state may include sheets of clay platelets 16 that are substantially adhered to each other. More specifically, FIG. 1A illustrates clay particles 14 in their natural state dispersed within a polymer matrix 18. FIG. 1B illustrates that the clay particles 14 in such an orientation may not present effective obstacles to penetrant molecules 20. As shown, the molecules 20 may easily move around the particle groupings 14 to pass through the material.

[0035] In FIG. 2 clay platelets 16 are shown oriented in an exfoliated, or delaminated, state. Individual platelets 16 of a clay particle 14 may be separated from each other and dispersed randomly within the polymer matrix 18. For example, and without limitation, a platelet 16 may have a generally planar shape that may be approximately 3 to 10 nanometers thick by several hundred to several thousand nanometers across.

[0036] Referring now to FIGS. 3A and 3B, exemplary clay platelets 16 are illustrated oriented in an exfoliated and aligned state. FIG. 3A illustrates platelets 16 that may be aligned relative to each other. Platelets 16 that are "aligned relative to each other", or "aligned", means platelets 16 that are substantially parallel to each other. For example, and

without limitation, when measured in the same coordinate system, the angle of one platelet 16 relative to an axis is within 0 to 20 degrees (such as 0 to 10 degrees) of the angle of the other platelet 16. Layers of polymer 18 may be disposed between the platelets 16. The platelets 16 may generally be positioned only a few nanometers apart, such as 1 to 5, 5 to 10, 10 to 15, and/or 15 to 20 nanometers apart. Platelets 16 that are aligned may be intercalated within a matrix such as a polymer matrix 18.

[0037] FIG. 3B illustrates that the minimal space between aligned platelets 16 may present obstacles to penetrant molecules 20. Both the exfoliated state FIG. 2 and the exfoliated and aligned state of FIG. 3A may represent improvements in the barrier properties of the resulting nanocomposite, but the exfoliated and aligned state typically provides more improvement.

[0038] In certain embodiments, clay minerals may be used as starting materials because they comprise particles 14 that may be converted into thousands of individual platelets 16. Examples of such clay minerals include phyllosilicate clay minerals (e.g., montmorillonite, hectorite, saponite, and bentonite), also known as sheet silicates. Examples of such clay include CLOISITE 20A®, Na+, 30B, 25A, Ca++, and 116. CLOISITE 20A® has an ammonium salt surfactant comprising dimethyl-dihydrogenated tallow quaternary ammonium salt.

[0039] Sheet silicates may comprise nanometer to micron scale particles 14, which themselves may comprise thousands of extremely thin mineral sheets loosely held together by Van der Waals forces. The sheets may be separated to form platelets 16 with large aspect ratios (e.g., 100:1 or greater), such as approximately 3 to 10 nanometers thick by several hundred to several thousand nanometers across. The material 14 may be permeable in the direction parallel to the platelets 16, but they may be essentially impermeable in the direction orthogonally through the platelets 16.

[0040] The small size of nanoparticles may allow them to influence the structure of a polymer in small amounts. A nanocomposite may contain particles with at least one nanoscale (10^{-9} meter) aspect (length, width, or thickness). Because of the enormous surface area of a dispersion of such particles, relatively small loadings (typically a few percent by weight) in a polymer matrix may exhibit orders of magnitude-scale improvements in certain physical properties, while minimally changing other properties.

[0041] For example, and without limitation, a small amount of platelet material may achieve a large decrease in permeability with minimal change in other physical properties of the polymer. The percentage of clay platelets to polymer by weight, or the platelet to polymer weight percentage, may be 10% or less, such

as between 2% to 8%, inclusive of the endpoints of the range. The addition of clay platelets may reduce permeability by at least an order of magnitude and perhaps by a factor of 100.

[0042] Referring now to FIG. 4, an exemplary extrusion system 24 can be used to manufacture extruded products 26 according to certain embodiments. The extrusion system 24 may be used to create objects of a fixed cross-sectional profile from extrusion materials. The products of extrusion may generally be referred to as "extrudates." System 24 receives materials including exfoliated clay platelets 28 and polymeric substrate materials 30 at hoppers 32. These materials are mixed together in mixer 34. An extruder 36 applies a shear force to the mixed materials by forcing the materials through a die 38. Force can be applied by a ram, a pump, or gravity. Die 38 can produce extrudates having many known cross-sectional areas. Flat extrudates, hose extrudates, tape extrudates and the like are contemplated. Flow during the extrusion process aligns the clay platelets with one another in the flow direction. Aligned particles in the polymer matrix yield a material having improved resistance to permeability in a direction perpendicular to the aligned platelets. This can be further formed into a desired shape by pressing or rolling.

[0043] FIG. 5 shows a device 40 for providing polymer-clay nanocomposite continuously around an elongated object 42 such as

a wire or cable. The device 40 produces a coating 44 around elongated object 42. As described above, nanoparticle platelets 28 are received in a hopper 32, and raw polymer 30 is received in another hopper 32. Platelets 16 and polymer 30 are heated as necessary and mixed in mixer 34. The platelet and polymer mixer 34 provides the mixture to a jacket extruder 46. Jacket extruder also receives elongated object 42 for coating. Jacket extruder 46 has an appropriate die as known in the art for forming a coating 44 of the mixture around elongated object 42 as object 42 is pulled through extruder 46. During the coating process within jacket extruder 46 shear forces will cause alignment of the major dimension of the platelets in the direction that object 42 is being pulled. The mixture has the same viscosity as other thermoplastic polymer coatings nanoparticle, and jacket extruder 46 can be any jacket extruder device known in the art for coating a wire or cable with a polymer material. Thus, device 40 is capable of providing a coating 44 around object 42 in an extrusion region within the jacket extruder 46 wherein the coating 44 has layered nanoparticle platelets.

[0044] In other embodiments of the present invention, the extruder may use an actuator and a ram to push the mixed materials through a die. The mixed materials may be moved through the extruder in any suitable manner. For example, and without limitation, the extruder may be positioned in a vertical

manner, such that gravity may move material through the extruder. For example, and without limitation, the mixed material may remain stationary, while the extruder moves relative to the material.

[0045] Referring now to FIG. 6, a device 48 can be utilized for making polymer-clay nanocomposite pellets 52. As above, nanoparticle platelets 28 and raw polymer material 30 are provided in hoppers 32. These materials are heated and mixed in mixer 34. Extruder 36 shapes the material into a billet. Alignment of the platelets during extrusion is not critical in this embodiment. A chopper 50 chops the billet or other form into pellets 52. (The billet can be any shape to accommodate chopper 50.) Extruder 36 and chopper 50 can be devices currently known in the manufacture of polymer pellets. Nanocomposite pellets 52 can be used to manufacture nanocomposite polymer in a much simpler apparatus as described hereinafter.

[0046] FIG. 7 shows a device 54 for producing nanocomposite coatings from nanocomposite pellets 52. Nanocomposite pellets 52 are provided to a jacket extruder 46 which heats the pellets 52 and extrudes a coating 44 around an object 42 such as a wire or cable. Shear forces in the jacket extruder align nanocomposite platelets within the melted nanocomposite pellets 52. As the object 42 is pulled through jacket extruder 46, coating 44 is extruded on to object 42. Other extruders and dies

can be used for forming extrudates having aligned platelets as in FIG. 4.

[0047] FIG. 8 provides a flowchart showing an embodiment of the method for practicing the invention. From the start 100, additive clay particles are received in step 102. As described above, the clay can be a phyllosilicate mineral with clay particles 14 that may have silicate sheets that can form the clay platelets 16. In certain embodiments, the clay particles 14 may be heated at any suitable temperature and placed in a vacuum for any suitable amount of time. For example, and without limitation, the clay particles 14 may be heated in an oven (without vacuum) at 100 to 120 degrees Celsius (such as 110 degrees Celsius) for 30 to 60 minutes (such as 45 minutes). The clay particles 14 may then be exposed to a vacuum of 28 to 31 inches of Mercury (in-Hg) (such as 30 in-Hg) and dried for 90 to 120 minutes.

[0048] The clay particles 14 may be pretreated at step 104 to make the clay platelets 16 more compatible with the polymer. Clay minerals typically may contain cations (e.g., Na⁺, Li⁺, and Ca²⁺) between the clay platelets 16. In certain embodiments of the present invention, chemical pretreatment may convert normally hydrophilic silicate surfaces of the platelets 16 into organophilic surfaces that may be compatible with polymers. Examples of pretreatments may include pretreating with an ion

exchange reaction with an organic cation, an alkylammonium ion, and/or a silane ion.

[0049] The polymer may be provided at step 106. The polymer may be a polyurethane, such as a thermoplastic polyurethane (TPU). In certain embodiments, the polymer may be provided as a polymer resin. In certain embodiments, the polymer may be heated at any suitable temperature and placed in a vacuum for any suitable amount of time. In certain embodiments, the polymer may be heated and placed in a vacuum as described with reference to step 102.

[0050] The clay particles 14 and polymer may be mixed at step 108 to exfoliate the clay platelets 16 to yield a polymer-clay nanocomposite. As the ingredients are mixed, the polymer may infiltrate between the individual clay platelets 16. The weight percentage of the clay particles 16 to polymer may be less than 10%, e.g., in a range of 2% to 8% (inclusive of the endpoints of the range), such as 5%. For example, and without limitation, 44.65 g polymer and 2.45 g clay may be used to yield an approximately 5% weight percentage.

[0051] The polymer and platelets 16 components may be mixed in any suitable manner in any suitable mixer (e.g., a mixer with blades such as roller-type mixing blades). In certain embodiments, the mixer may be preheated, such as to 125 degrees Celsius. The components may be added in any suitable order

(e.g., first approximately half the polymer, then the clay, and then the rest of the polymer). The blades may rotate at any suitable rotations per minute (RPM) for any suitable amount of time. For example, and without limitation, the RPM may be lower (e.g., 30 RPM) while the components may be added to the mixer, then may be increased to a higher RPM (e.g., 60 RPM) until the components are mixed (e.g., 10 to 30 minutes, such as 20 minutes), and then may be decreased to a lower RPM (e.g., 30 RPM). A curing agent (e.g., diamine curing agent) may be added to the mixture. The mixture is formed into a billet in step 110 by means known in the art. This could be by extruding or setting in a form.

[0052] The polymer-clay nanocomposite may be pelletized at step 112 to yield polymer-clay nanocomposite pellets 52. The nanocomposite may be pelletized from the billet in any suitable manner using any suitable device (e.g., a rotary mill, grinder, reclaimer, and/or sharp blade). In certain embodiments, the nanocomposite may be reshaped while still hot, but sufficiently cooled to be less sticky. The nanocomposite may be formed into another shape more convenient for further processing. For example, and without limitation, a long rod shape may allow for more convenient pelletizing, and a flat rectangular shape may allow for more convenient sectioning and storage.

[0053] In certain embodiments, the nanocomposite (which may be reshaped) may be pelletized by a mill or grinder, or may be cut into pieces with a sharp blade. The pelletizing may yield pellets 52 having any suitable shape and size. In certain embodiments, the pellets may be a shape and size that may be readily accommodated by an extrusion system. For example, and without limitation, a pellet may have a generally rounded shape, (e.g., a shape where the longest diameter and shortest diameter differ by less than 25%, less than 15%, or less than 5%). For example, and without limitation, the pellets may be a size where the longest diameter may be less than one inch, less than $\frac{1}{2}$ inch, or less than $\frac{3}{16}$ inch, such as $\frac{1}{8}$ inch. Nanocomposite pellets 52 made from step 112 can be provided to another location for forming the material.

[0054] At a desired location for forming the material, pellets 52 can be heated to melt the polyurethane substrate in step 114. This method may be used to manufacture any suitable extruded product, such as a hose or a cable covering. After heating, the nanocomposite material can be extruded in step 116. Extrusion will shear the nanocomposite material as described above in order to align the nanoparticle platelets. Ordinary extrusion methods known in the art can be used because the entrained nanoparticle platelets do not affect the mechanical properties of the polyurethane.

[0055] Exemplary embodiments may include application of the nanocomposite material to any suitable product to improve impermeability. Nanocomposite material can also preserve material clarity at visible light wavelengths while being impenetrable at other wavelengths such as ultraviolet wavelengths. This can be selected by selecting platelet size. Examples of products may include products designed to be impermeable to fluids (gas and/or liquid), such as coatings, hoses, cable jackets, connector encapsulants, tennis ball cores, and pressurized caps for carbonated fluids. The barrier material may be applied to the product in any suitable manner. For example, a polymer-clay nanocomposite may be added to an extrusion channel as a solid mixture. As another example, the polymer-clay nanocomposite may first be pelletized and then added to the extrusion channel as pellets. The barrier material may be provided in any suitable manner for use with a product. For example, the barrier material may be applied to an extrusion material to form a ribbon extrudate. The ribbon may be wrapped around a product to improve the impermeability of the product.

[0056] Certain features of the embodiments may be advantageous in solving the problems described herein, as well as other problems that are discoverable by a skilled artisan. A relatively small amount of the polymer-clay nanocomposite may greatly improve barrier properties of polymer. Fillers added to

a polymer may degrade desired properties, so smaller amounts may be less likely to degrade such properties. Improved barrier protection may prevent, or at least significantly slow down, product degradation, thereby extending the usable service lifetime of the product. For example, cathodic delamination may be prevented or slowed, extending the service life of marine products such as naval sensors and sonar systems. Known extrusion systems already utilize additives provided in pelletized form. Thus, these systems may more readily incorporate the pelletized form of the polymer-clay nanocomposite described herein into their extrusion process.

[0057] Although this disclosure has been described in terms of certain embodiments, modifications (such as changes, substitutions, additions, omissions, and/or other modifications) of the embodiments will be apparent to those skilled in the art. Accordingly, the modifications may be made to the embodiments without departing from the scope of the invention.

[0058] Examples of modifications apparent to those skilled in the art include, but are not limited to, the following: components of the embodiments may be integrated or separated; operations of the embodiments may be performed by more, fewer, or other components; methods may include more, fewer, or other steps; the steps of a method may be performed in any suitable order; equivalents may be substituted for certain elements of

the embodiments; and modifications may be made to adapt embodiments to a particular situation.

[0059] Although specific terms may have been employed in the drawings and description, they are unless otherwise stated used in a generic and descriptive sense only and do not limit the scope of the invention. For example, "first", "second", etc. do not denote any order or importance, but merely distinguish one element from another. In addition, "a", "an", etc. do not denote a limitation of quantity, but rather the presence of at least one of the referenced item.

[0060] Thus, the scope of the invention should be determined by the appended claims and their legal equivalents, and not by the examples given.

POLYMER-CLAY NANOCOMPOSITE METHOD

ABSTRACT OF THE DISCLOSURE

A method for forming a polymer coating utilizes phyllosilicate clay particles and a thermoplastic polymer. The particles are treated to make them organophilic. The treated particles are then mixed with heated polymer. Mixing exfoliates the particles into platelets in the polymer to give a nanocomposite polymer. The nanocomposite polymer is then extruded into a coating. Extrusion in a desired direction providing improved barrier properties for the coating. The coating can be extruded over an object. Nanocomposite polymer can also be provided as pellets for melting and extrusion.

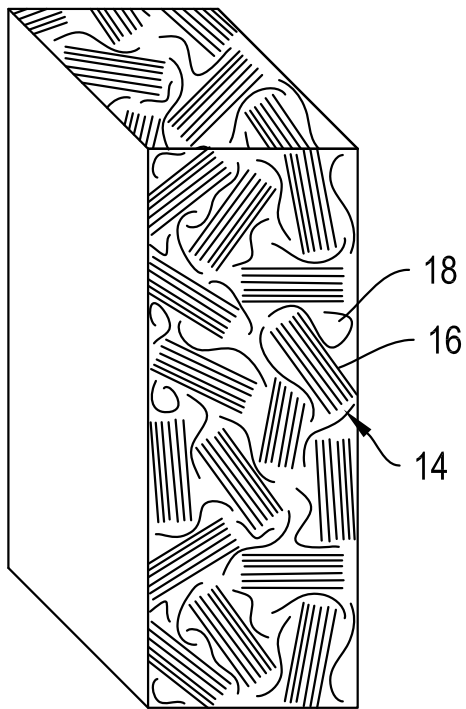


FIG. 1A

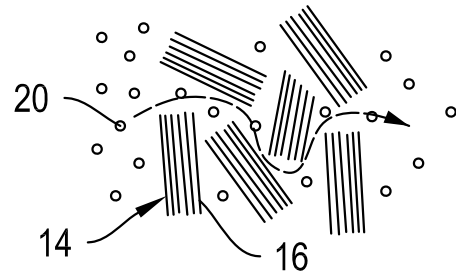


FIG. 1B

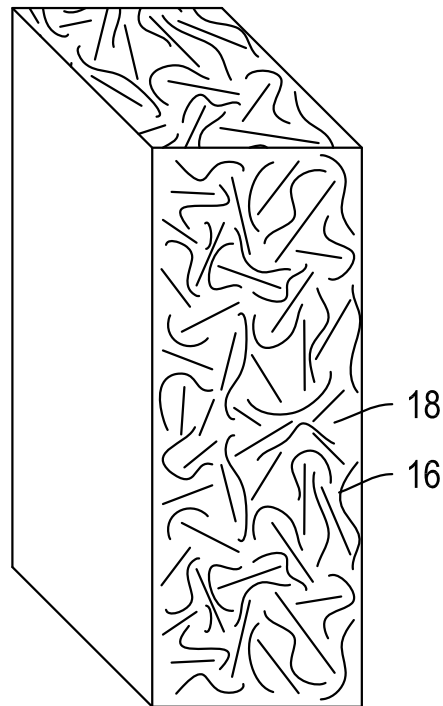


FIG. 2

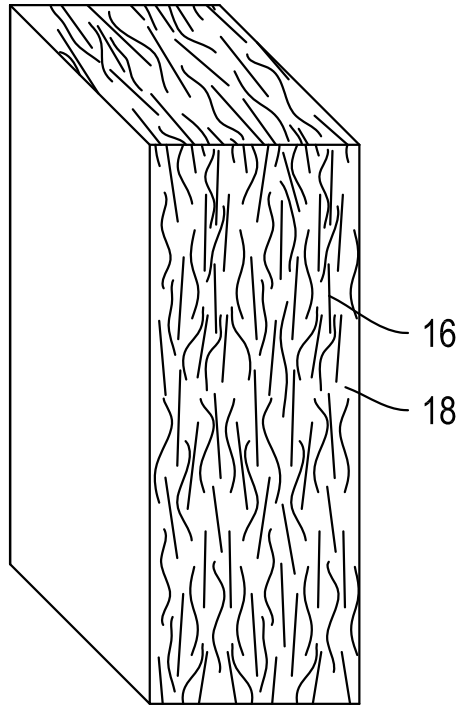


FIG. 3A

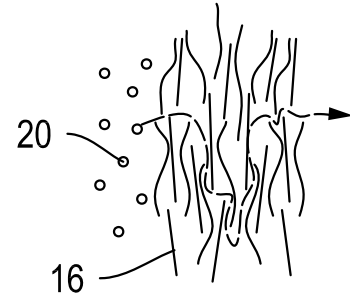


FIG. 3B

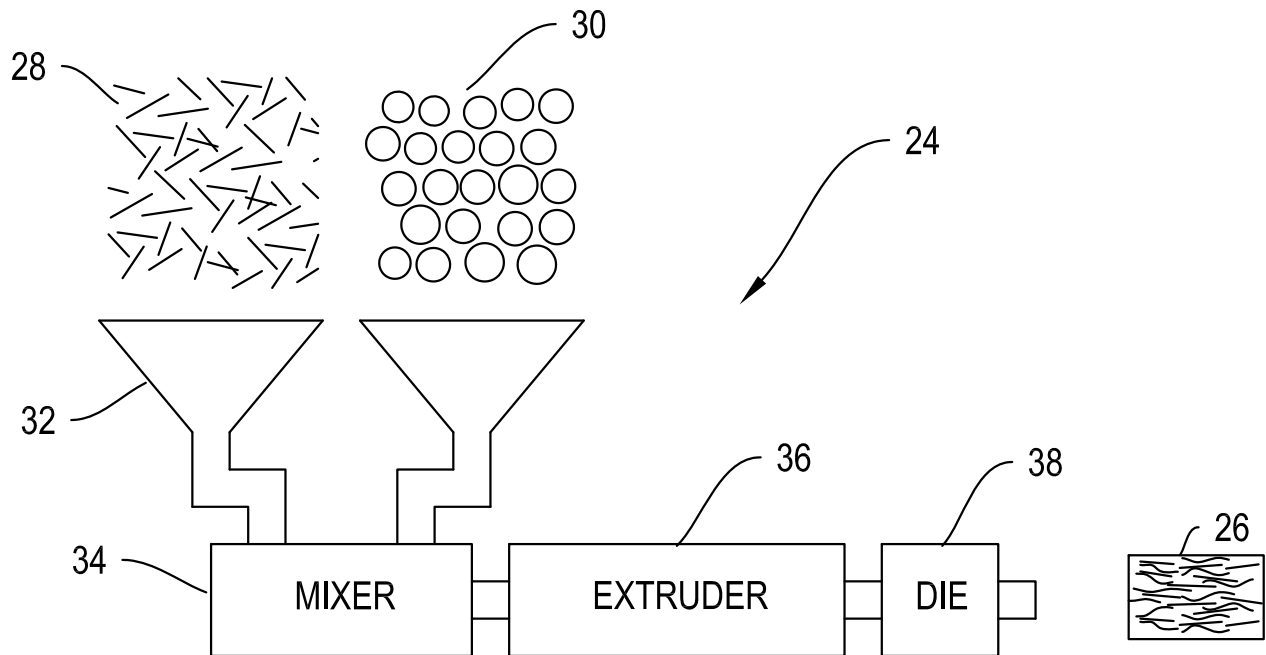


FIG. 4

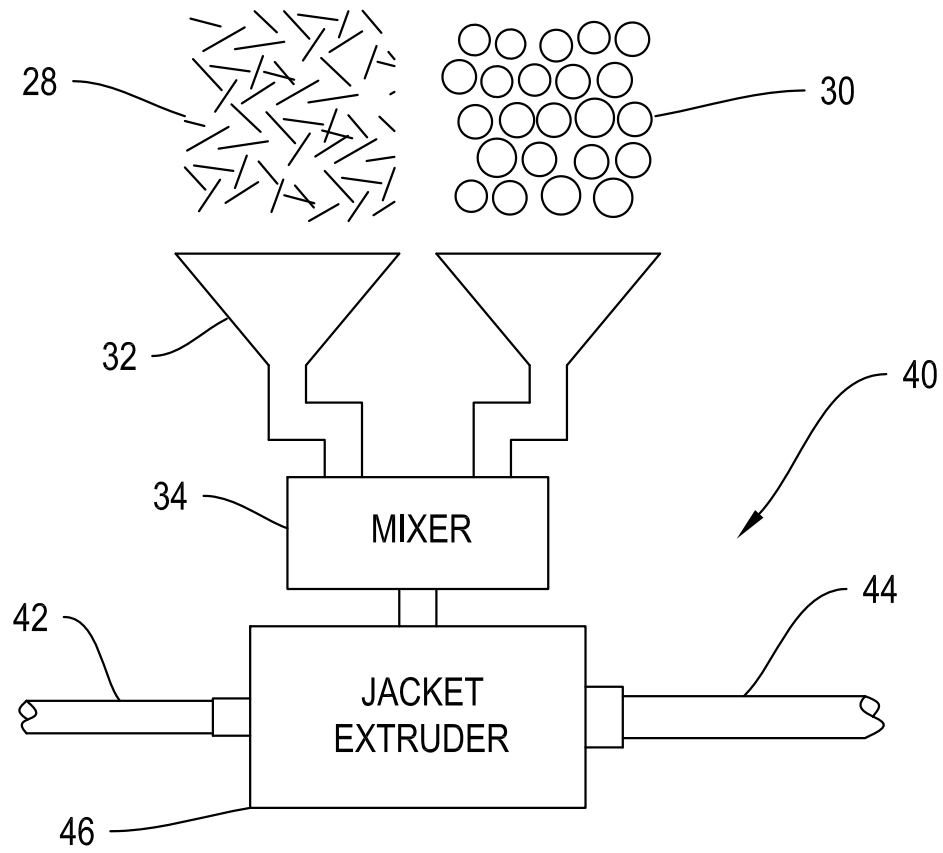


FIG. 5

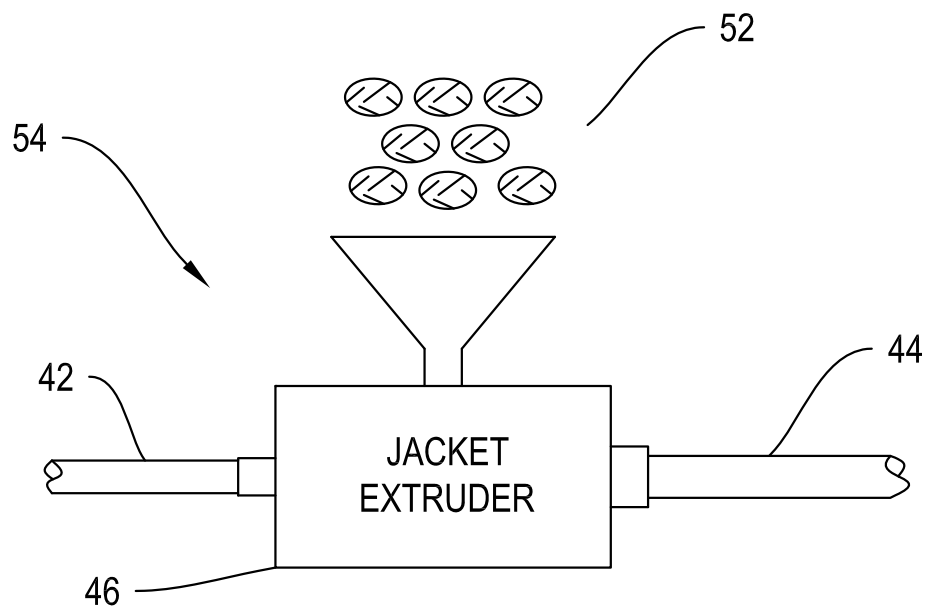


FIG. 7

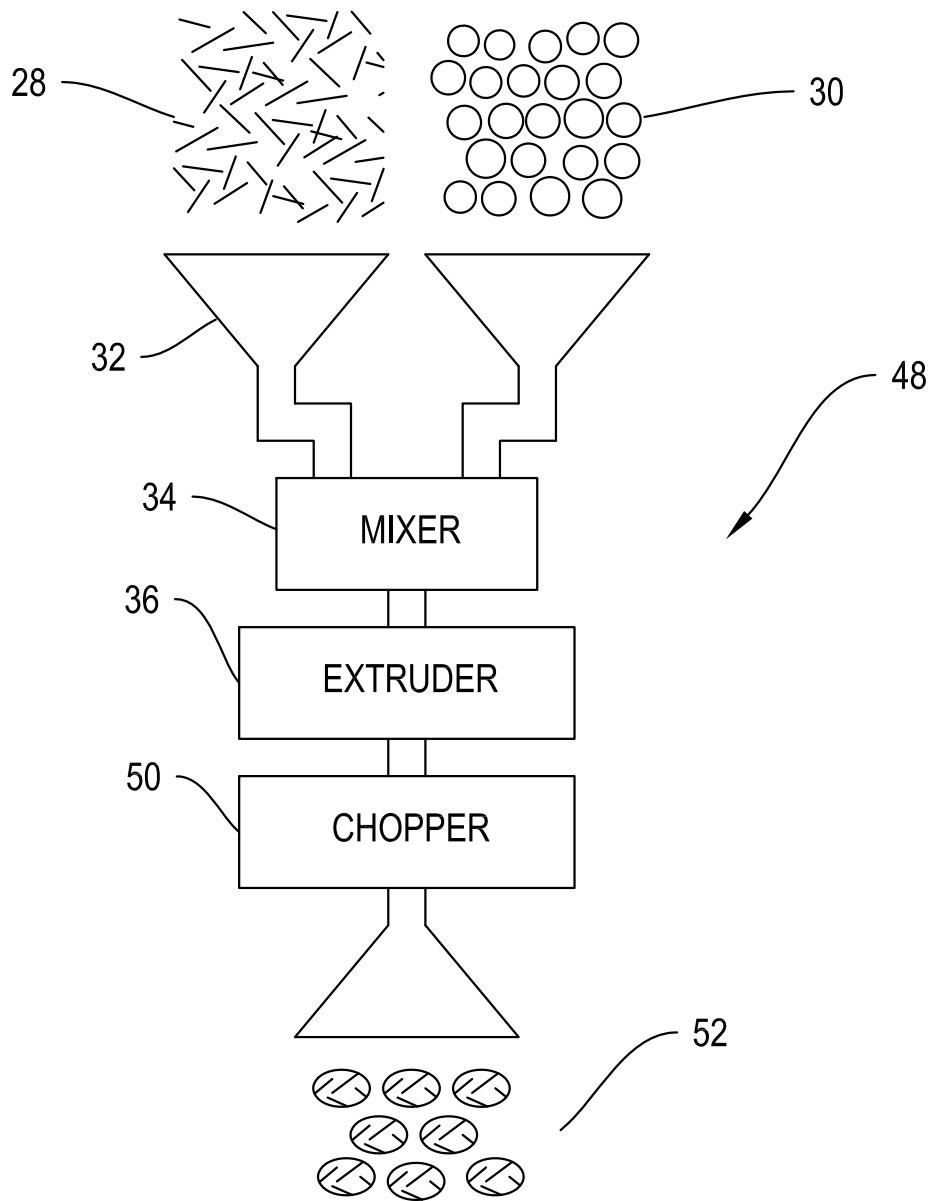


FIG. 6

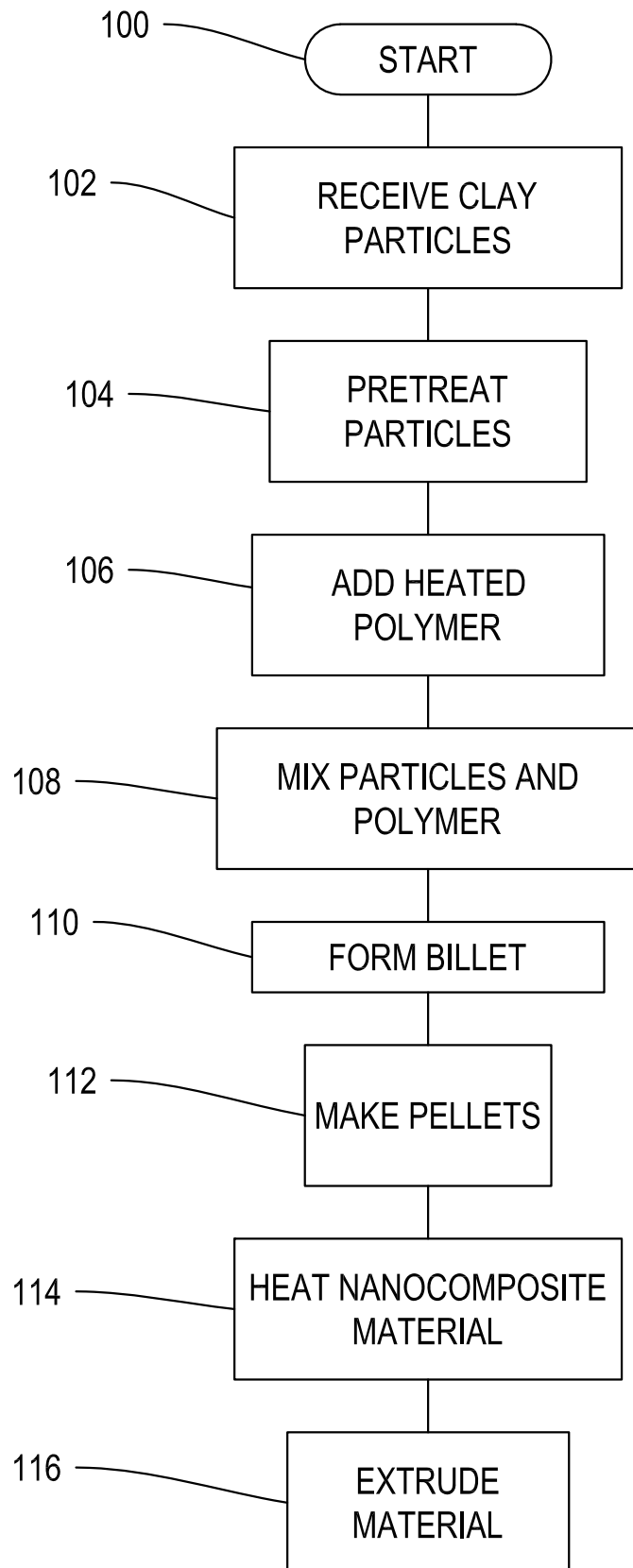


FIG. 8