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(54) Title: METHODS AND APPARATUSES FOR ADDITIVELY MANUFACTURING RUBBER

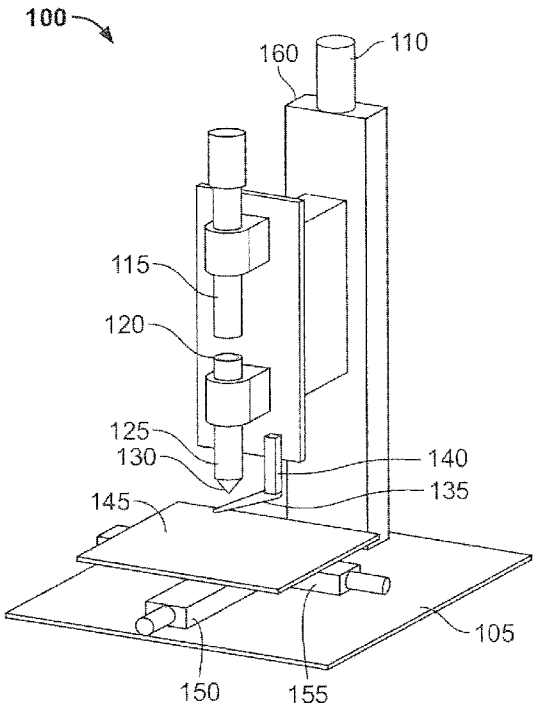


FIG. 1

(57) Abstract: An apparatus, system, and method for disposing green rubber, via 3D Printing or additive manufacturing, are provided. The apparatus includes at least a housing, a nozzle, and a heating element. Green rubber is forced through the nozzle and deposited in an iterative build process. The apparatus may be used in a variety of applications, including tire applications.

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METHODS AND APPARATUSES FOR ADDITIVELY MANUFACTURING RUBBER

FIELD OF INVENTION

[1] The present disclosure is directed to methods and apparatuses for providing shaped objects containing green or un-vulcanized rubber. More particularly, the present disclosure is directed to 3D printing or additive manufacturing methods and apparatuses for providing shaped objects made with green or un-vulcanized rubber. The printed or manufactured rubber may be used in a variety of applications, including tire applications.

BACKGROUND

[2] Known methods and apparatuses of 3D Printing, which is also referred to as additive manufacturing, utilize polymeric materials, such as polyactic acid (PLA), acrylonitrile butadiene styrene (ABS), or nylon, or metals, such as steel. Methods and apparatuses used in 3D printers vary by material used in the printer. Thus, specific methods and apparatus components are implemented to deliver a useful product.

SUMMARY OF THE INVENTION

[3] In one embodiment, an apparatus for disposing green rubber includes a housing comprising a base and at least one support structure, an inlet for receiving green rubber from an external source, and a nozzle for disposing green rubber. The nozzle is mounted to the support structure and receives green rubber from the external source via a path from the inlet. A heating element and a regulator configured to maintain the temperature of green rubber in the apparatus below a predetermined setpoint, a cutting instrument mounted to the apparatus and configured to separate green rubber dispensed from the nozzle, a propulsion assembly that forces green rubber through the nozzle, a build surface upon which green rubber is disposed, and an actuator capable of moving at least one of the nozzle and the build surface are also included.

[4] In another embodiment, a system for the additive manufacturing of green rubber is provided. The system comprises an electronic machine that facilitates control of a printing apparatus by a software system, wherein the printing apparatus comprises a hopper, a feeder, a line, a thermal regulator, an egress, a printing surface, and a motion control assembly, and the software system comprises at least one software module that receives user input selecting specifications for a three-dimensional object, at least one software module that retrieves specifications for a three-dimensional object, at least one software module that creates control commands based on the received and retrieved specifications, and at least one software module that executes control commands effectuating motion in the motion control assembly.

[5] In another embodiment, a method of additively printing green rubber comprises providing power to a printing apparatus, providing un-vulcanized rubber to the printing apparatus, providing a plasticizer to the printing apparatus, wherein the plasticizer is an additive or oil, decreasing the viscosity of at least one of the materials provided to the printing apparatus by warming, pressurizing the green rubber provided to the printing apparatus to a pressure of at least 5,500 kPa, identifying a three dimensional structure to be printed by the printing apparatus, identifying a series of motion commands to build the three dimensional structure, positioning a dispenser at the beginning of the series of motion control commands, commencing an iterative build process comprising the steps of dispensing green rubber over an area and separating dispensed green rubber from the dispenser, terminating the iterative build process, and removing the printed rubber from the printing apparatus.

BRIEF DESCRIPTION OF THE DRAWINGS

[6] In the accompanying drawings, structures are illustrated that, together with the detailed description provided below, describe exemplary embodiments of the claimed invention. Like elements are identified with the same reference numerals. It should be understood that elements shown as a single component may be replaced with multiple components, and elements shown as multiple components may be replaced with a single component. It should also be

understood that steps in a method shown as a single step may be replaced with multiple steps, steps shown as multiple steps may be replaced with a single step, and the ordering of certain steps may be varied without altering the method. The drawings are not to scale and the proportion of certain elements may be exaggerated for the purpose of illustration.

[7] **Figure 1** is a perspective view of one embodiment of an apparatus for 3D printing or additively manufacturing a rubber article;

[8] **Figure 2** is a perspective view of a system for the additive manufacturing of rubber, and;

[9] **Figure 3** is a flow chart detailing the steps of a method for additively printing rubber.

DETAILED DESCRIPTION

[10] The following includes definitions of selected terms employed herein. The definitions include various examples and/or forms of components that fall within the scope of a term and that may be used for implementation. The examples are not intended to be limiting. Both singular and plural forms of terms may be within the definitions.

[11] "3D printer" refers to a machine used for 3D printing.

[12] "3D printing" refers to the fabrication of objects through the deposition of a material using a print head, nozzle, or another printer technology.

[13] "3D scanning" refers to a method of acquiring the shape and size of an object as a three-dimensional representation by recording spatial coordinates on the object's surface.

[14] "Additive manufacturing" or "AM" refers to a process of joining materials to make objects from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing methodologies. Additive manufacturing includes 3D printing, binder jetting, directed energy deposition, fused deposition modeling, laser sintering, material jetting, material extrusion, powder bed fusion, rapid prototyping, rapid tooling, sheet lamination, and vat photopolymerization.

[15] "Additive systems" refer to machines used for additive manufacturing.

[16] "Binder jetting" refers to an additive manufacturing process in which a liquid bonding agent is selectively deposited to join powder materials.

[17] "Computer-Aided Design" or "CAD" refers to use of computers for the design of real or virtual objects.

[18] "Computer-Aided Manufacturing" or "CAM" typically refers to systems that use surface data to drive CNC machines, such as digitally-driven mills and lathes, to produce parts, molds, and dies.

[19] "Computer Numerical Control" or "CNC" refers to computerized control of machines for manufacturing.

[20] "Directed energy deposition" refers to an additive manufacturing process in which focused thermal energy is used to fuse materials by melting as they are being deposited.

[21] "Facet" refers to a three- or four-sided polygon that represents an element of a 3D polygonal mesh surface or model.

[22] "Focused thermal energy" refers to an energy source (e.g., laser, electron beam, or plasma arc) that is focused to melt the materials being deposited.

[23] "Fused deposition modeling" refers to a material extrusion process used to make thermoplastic parts through heated extrusion and deposition of materials layer by layer.

[24] "Laser sintering" or "LS" refers to a powder bed fusion process used to produce objects from powdered materials using one or more lasers to selectively fuse or melt the particles at the surface, layer by layer, in an enclosed chamber.

[25] "Material extrusion" refers to an additive manufacturing process in which material is selectively dispensed through a nozzle or orifice.

[26] "Material jetting" refers to an additive manufacturing process in which droplets of build material are selectively deposited. Example materials include, without limitation, photopolymer and wax.

[27] "Powder bed fusion" refers to an additive manufacturing process in which thermal energy selectively fuses regions of a powder bed.

[28] "Rapid prototyping" refers to additive manufacturing of a design, often iterative, for form, fit, or functional testing, or combination thereof.

[29] "Rapid tooling" refers to the use of additive manufacturing to make tools or tooling quickly, either directly, by making parts that serve as the actual tools or tooling components, such as mold inserts, or indirectly, by producing patterns that are, in turn, used in a secondary process to produce the actual tools.

[30] "Reverse engineering," in the additive manufacturing context, refers to a method of creating a digital representation from a physical object to define its shape, dimensions, and internal and external features.

[31] "Sheet lamination" refers to an additive manufacturing process in which sheets of material are bonded to form an object.

[32] "STL" refers to a file format for 3D model data used by machines to build physical parts.

[33] "Subtractive manufacturing" refers to making objects by removing of material (for example, buffing, milling, drilling, grinding, carving, etc.) from a bulk solid to leave a desired shape, as opposed to additive manufacturing.

[34] "Surface model" refers to a mathematical or digital representation of an object as a set of planar or curved surfaces, or both, that may or may not represent a closed volume.

[35] "Tool" or "Tooling" refers to a mold, die, or other device used in various manufacturing and fabricating processes such as plastic injection molding, thermoforming, blow molding, vacuum casting, die casting, sheet metal stamping, hydroforming, forging, composite lay-up tools, machining and assembly fixtures, etc.

[36] "Vat photopolymerization" refers to an additive manufacturing process in which liquid photopolymer in a vat is selectively cured by light-activated polymerization.

[37] While similar terms used in the following descriptions describe similar components and steps, it is understood that because the terms carry slightly different connotations, one of ordinary skill in the art would not consider any one

of the following terms to be purely interchangeable with another term used to describe a similar component or step.

[38] **Figure 1** shows a perspective view of a simplified apparatus **100** for 3D printing green rubber. As one of ordinary skill in the art will understand, apparatus **100** could be a 3D printer or additive system.

[39] As shown, the apparatus **100** features a base **105** and support structure **110**. As shown, the housing extends from the stabilizing base **105** and partially encompasses part of the support structure **110**. In an alternative embodiment (not shown), a housing completely encompasses some, or all of, the support structure. In another alternative embodiment (also not shown), the housing and support structure are an integral unit. In yet another alternative embodiment (also not shown), the housing and support structure are part of an assembly line.

[40] As shown, support structure **110** is a column. Support structure **110**, which may be made from a variety of materials, helps keep apparatus **100** upright. Support structure **110** may be mechanized or stationary. In an alternative embodiment (not shown), the support structure is a robotic arm. In another embodiment (also not shown), the support structure is a component of a robotic arm.

[41] Apparatus **100** contains ram **115** and inlet **120**. Green rubber is fed into the apparatus, or into a separate reservoir in the apparatus, and ram **115** imparts an applied force that moves the rubber through apparatus **100**. Ram **115** imparts an applied force by translating linearly. In a specific embodiment, ram **115** feeds green rubber from an external source through inlet **120** by imparting an applied force that moves green rubber into apparatus **100**. As one of ordinary skill in the art will understand, a number of shapes may be used for the ram. In another alternative embodiment (also not shown), the ram is replaced with an extruder (e.g., a screw-driven extruder), a pump, or drive.

[42] In the illustrated embodiment, inlet **120** is round, and its cross sectional area is slightly greater than the cross sectional area of the ram. As one of ordinary skill in the art will understand, a number of shapes may be used for the inlet, and the difference between the inlet and the green rubber introduced to the

apparatus may be varied as well. Thus, the external green rubber introduced into the apparatus may be a filament, ribbon, sheet, or other form of matter. In an alternative embodiment (not shown), a single inlet is replaced with two or more inlets. In an additional alternative embodiment (also not shown), the inlet is replaced with an intake that helps move material into the apparatus.

[43] As shown, apparatus **100** also contains barrel **125** that is disposed generally upright. As one of ordinary skill in the art will understand, though, a number of shapes may be used for barrel **125**, and barrel **125** could be disposed obliquely rather than upright. In an alternative embodiment (not shown), the barrel is integrated into, or combined with, other components of the apparatus.

[44] The materials in barrel **125** are pressurized. In one embodiment, the materials in the barrel are between 1,300–22,000 kPa. In another embodiment, the materials in the barrel are pressurized to at least 5,500 kPa. A propulsion assembly, such as the ram or an alternative embodiment, can be used to pressurize various chambers in the apparatus.

[45] In further alternative embodiments (not shown), barrel **125** contains mixing elements that agitate the green rubber. Examples of mixing elements include, without limitation, stirrers and impellers. As one of ordinary skill in the art will understand, mixing elements can be incorporated into other components of the apparatus.

[46] Barrel **125** may contain temperature control elements capable of conductive, convective, or radiant heating. In one embodiment, exemplary temperature control elements include, without limitation, resistive heating coils, liquid heating baths, and heat lamps that surround the barrel. Fans or chilled liquids may be used to reduce heat transfer to other parts of the apparatus if cooling is desired. As one of ordinary skill in the art will understand, temperature control elements can be integrated into, or combined with, other components of the apparatus.

[47] With continued reference to **Figure 1**, green rubber exits from barrel **125** via nozzle **130**. The nozzle **130** directs the flow of green rubber from the apparatus for material extrusion. The nozzle may be fixed or adjustable in size,

shape, or orientation. Likewise, the nozzle may be unitary with apparatus **100** or replaceable. The nozzle may also contain temperature control elements. As one of ordinary skill in the art will understand, varying the nozzle properties can impact resolution or volume-performance attributes of the apparatus.

[48] As shown, apparatus **100** contains a cutting instrument **135**. Cutting instrument **135** is a metal blade that separates green rubber from the nozzle. Cutting instrument **135** is affixed to the barrel and is controlled remotely (e.g., translated, rotated, or oscillated). In an alternative embodiment (not shown), the cutting instrument is affixed to the support structure. In an additional embodiment (also not shown), two blades are used to separate green rubber from the nozzle. In additional alternative embodiments, the cutting instrument may be, without limitation, a laser, liquid, plasma, or pneumatic cutter. As one of ordinary skill in the art will understand, the cutting element can be integrated into, or combined with, other components of the apparatus.

[49] When a cutting instrument is used, apparatus **100** may contain at least one vibration transducer **140**. The vibration transducer **140** may vibrate the nozzle **130** or the cutting instrument **135**. Alternatively, the nozzle and the cutting instrument may each utilize a dedicated vibration transducer. As one of ordinary skill in the art will understand, vibrating the nozzle enhances control of material extrusion by reducing friction at the nozzle, and vibrating the cutting instrument allows for a cleaner separation of material from the nozzle. In one embodiment, the vibration transducer operates ultrasonically, around 15–50 kHz. In an alternative embodiment, the nozzle and a metal blade cutting instrument are vibrated concurrently.

[50] Apparatus **100** also contains a build surface **145**. Build surface **145** is an object upon which the nozzle disposes green rubber. As shown, build surface **145** is a flat, metal plate. As one of ordinary skill in the art will understand, the build surface may be made from a variety of materials, in a variety of textures. In one embodiment, the build surface is pre-formed to facilitate construction of a particular object. In another alternative embodiment (also not shown), a support surface is used to aide structure retention at the build surface. The support surface

may be a simple structure with one surface (curved or flat) or a complex structure with multiple surfaces. In additional alternative embodiments (also not shown), the build surface is made of rubber, and printed green rubber is disposed on this surface. In a specific version of these alternative embodiments, the build surface is a strip of green rubber, such as a base tread layer.

[51] Apparatus **100** also features a plurality of actuators **150**, **155**, and **160**. Actuators **150** and **155** move build surface **145** in a horizontal plane. Actuator **160** moves build surface **145** vertically. Additional actuators may be used to move the barrel or the nozzle. As one of ordinary skill in the art will understand, the actuators used can be varied on an application-by-application basis.

[52] Although not shown in **Figure 1**, apparatus **100** may also contain reservoirs for materials used in connection with green rubber. Examples of these materials include, without limitation, oils, plasticizers, and additives. The apparatus may also contain two or more nozzles to facilitate printing a single object with multiple compounds or to facilitate providing various finishes or coatings. Thus, the apparatus could contain a first nozzle loaded with a first compound, and a second nozzle loaded with a second compound. It is generally understood that the apparatus is controlled by an electronic machine, such as a computer or similar device.

[53] **Figure 2** is a perspective view of a system **200** for 3D printing green rubber. As one of ordinary skill in the art will understand, system **200** is an additive system, and is not a portable 3D printer.

[54] As shown, system **200** comprises an electronic machine **205** and a printing assembly **210**. While the electronic machine **205** is illustrated as a desktop computer, it should be understood that the electronic machine may be, without limitation a computer, a tablet, a smartphone, a programmable logic controller (PLC), a computer numerical control (CNC) machine controller.

[55] Printing assembly **210** comprises multiple components. Green rubber is loaded into hopper **215**. The green rubber loaded into the hopper is in granular, pellet, bulk, or sheet form. In alternative embodiments (not shown), other forms of green rubber are used. In another alternative embodiment (not shown), an

agitator, such as a stirrer, is used to agitate the green rubber in the hopper. In yet another embodiment, the hopper is replaced with a spool loaded with green rubber.

[56] Printing assembly **210** also comprises feeder **220** that moves green rubber into printing assembly **210** by applying a force that pushes the green rubber down hopper **215**. In an alternative embodiment (not shown), the feeder pulls green rubber into the printing assembly. In another alternative embodiment, gravity pulls green rubber in the printing assembly and the feeder regulates the amount of green rubber that enters the printing assembly. In an alternative embodiment utilizing a spool (not shown), the feeder creates movement that allows the green rubber to move into the printing assembly.

[57] Printing assembly **210** further comprises a line **225**. Line **225** allows the rubber to move from the hopper (or another starting point). As shown, line **225** is open to hopper **215**. In an alternative embodiment (not shown), a rotating door partitions the line from the hopper. As one of ordinary skill in the art will understand, the line may be pressurized, and utilize a valve or pressure regulator is one way to maintain pressure in the line.

[58] Printing assembly **210** also contains a thermal regulator **230** that controls temperature in the line. Thermal regulator **230** includes a temperature sensor **235** and a temperature control element **240**. Temperature senor **235** is used to measure the temperature of materials in the line. Alternatively, the temperature sensor may be used to measure the temperature of the line wall, which may be used to estimate the temperature of the materials in the line. Exemplary temperature sensors include, without limitation, thermocouples, resistive temperature devices, thermometers, and infrared sensors.

[59] The temperature observed in temperature sensor **235** is sent to a device that compares the observed temperature to a preset value (or range of values). The comparing device may be, without limitation, an onboard processor on the thermal regulator **230**, the electronic machine **205**, or an external device (not shown). If the observed temperature is below the preset value, the device sends a signal causing temperature control element **240** to add heat. If the temperature is

above the present value, the device sends a signal causing the temperature control element **240** to remove heat or to shut off. As one of ordinary skill in the art will understand, a thermal regulator may be integrated into, or combined with, other components of the apparatus.

[60] Printing assembly **210** further comprises an egress **245** through which the green rubber exits. As shown, egress **245** is an opening. In alternative embodiments (not shown), the egress may be a nozzle or a slit for sheet lamination. In another alternative embodiment (not shown), the egress further comprises a ring and circular blade, akin to a guillotine cutter, that separates rubber from the egress. It should be understood that the egress may be open, partially shut, or fully shut.

[61] Printing assembly **210** further comprises printing surface **250**. Material exiting egress **245** is disposed on printing surface **250**. In the embodiment shown, the printing surface **250** is a series of rigid, flat planes. In an alternative embodiment (not shown), printing surface **250** is a belt. In additional alternative embodiments (not shown), printing surface **250** is a tire carcass. The tire carcass may be any type of tire.

[62] Printing assembly **210** further comprises a motion control assembly **255** that coordinates movement in the printing assembly. In one embodiment (not shown), the motion control assembly is part of the electronic machine. In another embodiment (not shown), the motion control assembly stands alone from the electronic machine.

[63] Although not shown, printing assembly **210** may further comprise one or more subtractive manufacturing elements. Examples of subtractive manufacturing elements include, without limitation, buffers, carvers, drills, grinders, lasers, and mills.

[64] Although not shown, printing assembly **210** may further comprise a vulcanization chamber that is integral or in close proximity to printing assembly **210**. Suitable vulcanization chambers include autoclaves. As one of ordinary skill in the art will understand, alternative vulcanization chambers utilizing known vulcanization methods may be used as well.

[65] Printing assembly **210** receives instructions from electronic machine **205**. The instructions for the printing assembly are executed by software. In one embodiment, user input is received at the electronic machine. In another embodiment, input is received at the printing assembly.

[66] The input received includes specifications for a three dimensional object, such as a surface model, preferably in STL (binary or ASCII) or CAD format. The input received may also include information pertaining to the properties of the materials in the printing assembly. In one embodiment of the system, the input information is maintained in a database. The database may include, without limitation, specifications of known tire tread patterns.

[67] Once the specifications are obtained, the electronic machine or motion control assembly coordinates operation of the printing assembly to produce the object. As one of ordinary skill in the art will understand, operation of the printing apparatus may be adjusted according to the properties of the green rubber and other materials in the printing assembly.

[68] The electronic machine or printing assembly may also generate identification information imparted to the printed rubber. This allows organizations or consumers to track the printed rubber. Examples of imparting identification information includes, without limitation, printing an identification number that corresponds to a printing batch.

[69] **Figure 3** is a flow chart detailing the steps of a method **300** for additively manufacturing green rubber.

[70] In method **300**, step **305** comprises providing power to the system. The power may be alternating current or direct electrical current.

[71] In method **300**, step **310** comprises providing un-vulcanized rubber to the printing apparatus. As one of ordinary skill in the art will understand, many types of un-vulcanized rubber may be provided to the printing apparatus. In one embodiment, the un-vulcanized rubber may be provided continually. In a second embodiment, the un-vulcanized rubber is provided in batch increments. In either embodiment, the amount of rubber provided to the printing apparatus may be monitored with sensors. Additionally, an alert may be generated when the amount

of rubber being provided to the printing apparatus falls below or exceeds predetermined thresholds.

[72] In method **300**, step **315** comprises an optional step of providing an additive, oil, or plasticizer to the printing apparatus. The provided additive, oil, or plasticizer, or various combinations thereof, is introduced to the un-vulcanized rubber. In alternative embodiments, additive(s), oil(s), and plasticizer(s) are introduced to the un-vulcanized rubber before the un-vulcanized rubber is provided to the printing apparatus.

[73] In method **300**, step **320** comprises decreasing the viscosity of the materials provided to the printing apparatus. In particular, in this step, the viscosity is decreased by warming the materials in the printing apparatus.

[74] In one embodiment in which the materials are warmed, the temperature of the materials in the system does not exceed 100°C. In another embodiment, the temperature of the materials in the system is held below a predetermined threshold. For example, the temperature of the materials in the system may be held below a vulcanization threshold. As one of ordinary skill in the art will understand, the thresholds may vary based on the particular materials that have been introduced into the printing apparatus. In these embodiments, the temperature may be regulated by a setpoint control loop.

[75] In method **300**, step **325** comprises pressurizing the un-vulcanized rubber. In one embodiment, the un-vulcanized rubber is pressurized to at least 5,500 kPa. In another embodiment, the un-vulcanized rubber is pressurized between 1,300–22,000 kPa. Pressurizing the un-vulcanized rubber assists moving un-vulcanized rubber into and through the printing apparatus. In an optional step, pressure in the printing apparatus is monitored as a safety precaution. In another optional step, pressure in the printing apparatus is monitored to aid in the control of material extrusion or movement of rubber through the apparatus or as an estimate of the viscosity of the materials in the printing apparatus.

[76] In method **300**, step **330** comprises identifying a three dimensional structure, such as a surface model to be printed by the printing apparatus. Exemplary designs include, without limitation, CAD designs and original designs.

In one embodiment, the three dimensional structure is obtained via 3D scanning. In an alternative embodiment, the three dimensional structure is obtained via reverse engineering. In another embodiment, the three dimensional structure is obtained from a design database of facet models. Examples of three dimensional structures include, without limitation, bellows, consumer goods, dampers, industrial components (such as gaskets, grommets, or o-rings), shoe components, and tire components (such as a tread or lug).

[77] In method **300**, step **335** comprises selecting options and settings for a build process. In this step, options and settings including, without limitation, materials used, and printing resolution are selected.

[78] In method **300**, step **340** comprises identifying (or directing creating of) motion control commands to build the three dimensional object. Once the commands are identified, a dispenser is positioned at a starting position.

[79] In method **300**, step **345** comprises commencing an iterative build process, where steps of dispensing un-vulcanized rubber and separating un-vulcanized rubber from the dispenser are repeated iteratively. The iterative build process is dictated by the motion control commands of step **340**. Optionally, a support may be used to buttress dispensed un-vulcanized rubber. In one embodiment of the iterative build process, the iterative build process further comprises a positioning step that at least moves a dispenser vertically.

[80] In method **300**, step **350** comprises terminating the iterative build process. Terminating the build process concludes movement of the dispenser. Optionally, terminating the build process may include a further processing step of applying a coating onto the printed article. In one embodiment, the iterative build process includes a further step of material jetting. In another embodiment, terminating the iterative build process includes a further step of fused deposition modeling, where a thermoplastic is disposed on at least a portion of the printed rubber. In another embodiment, terminating the iterative build process includes a further step of subtractive manufacturing. In yet another embodiment, terminating the iterative build process further includes an optional cooling step.

[81] In method **300**, step **355** comprises removing the printed rubber from the printing apparatus. In one embodiment, the removal is performed manually. In another embodiment, removal is automated (such as with a belt or robotic arm).

[82] In method **300**, step **360** comprises vulcanizing the printed rubber. In one embodiment, the vulcanization step is a complete vulcanization procedure that produces a final, fully-vulcanized product. In another embodiment, the vulcanization procedure is a partial vulcanization procedure.

[83] To the extent that the term "includes" or "including" is used in the specification or the claims, it is intended to be inclusive in a manner similar to the term "comprising" as that term is interpreted when employed as a transitional word in a claim. Furthermore, to the extent that the term "or" is employed (e.g., A or B) it is intended to mean "A or B or both." When the applicants intend to indicate "only A or B but not both" then the term "only A or B but not both" will be employed. Thus, use of the term "or" herein is the inclusive, and not the exclusive use. See, Bryan A. Garner, A Dictionary of Modern Legal Usage 624 (2d. Ed. 1995). Also, to the extent that the terms "in" or "into" are used in the specification or the claims, it is intended to additionally mean "on" or "onto." Furthermore, to the extent the term "connect" is used in the specification or claims, it is intended to mean not only "directly connected to," but also "indirectly connected to" such as connected through another component or components.

[84] While the present disclosure has been illustrated by the description of embodiments thereof, and while the embodiments have been described in considerable detail, it is not the intention of the applicants to restrict or in any way limit the scope of the appended claims to such detail. Additional advantages and modifications will readily appear to those skilled in the art. Therefore, the disclosure, in its broader aspects, is not limited to the specific details, the representative apparatus and method, and illustrative examples shown and described. Accordingly, departures may be made from such details without departing from the spirit or scope of the applicant's general inventive concept.

CLAIMS

What is claimed is:

1. An apparatus for disposing green rubber comprising:

a housing comprising a base and at least one support structure;

an inlet for receiving green rubber from an external source;

a nozzle for disposing green rubber, wherein the nozzle is mounted to the support structure and receives green rubber from the external source via a path from the inlet;

a heating element and a regulator configured to maintain a temperature of green rubber in the apparatus below a predetermined setpoint;

a cutting instrument mounted to the apparatus and configured to separate green rubber dispensed from the nozzle;

a propulsion assembly that forces green rubber through the nozzle;

a build surface upon which green rubber is disposed;

an actuator capable of moving at least one of the nozzle and the build surface.

2. The apparatus of claim 1, wherein the cutting instrument is a metal blade.

3. The apparatus of claim 1, further comprising at least one vibration transducer that vibrates the nozzle or the cutting instrument.

4. The apparatus of claim 1, wherein the heating element warms the nozzle and path through resistive heating.

5. The apparatus of claim 1, wherein the propulsion assembly pressurizes green rubber in the apparatus between 1,300 and 22,000 kPa.

6. The apparatus of claim 1, wherein the support structure is a robotic arm.

7. The apparatus of claim 1, wherein the apparatus further comprises a second nozzle for disposing viscous material.

8. The apparatus of claim 1, further comprising a belt configured to move dispensed green rubber from the apparatus.

9. A method of additively printing green rubber comprising,

providing power to a printing apparatus;

providing materials to the printing apparatus, the materials including un-vulcanized rubber and a plasticizer, wherein the plasticizer is an additive or oil;

decreasing a viscosity of at least one of the materials provided to the printing apparatus by warming;

pressurizing the un-vulcanized rubber provided to the printing apparatus to a pressure of at least 5,500 kPa;

identifying a three dimensional structure to be printed by the printing apparatus;

identifying a series of motion commands to build the three dimensional structure;

positioning a dispenser at a beginning of a series of motion control commands;

commencing an iterative build process comprising steps of dispensing un-vulcanized rubber over an area and separating dispensed un-vulcanized rubber from the dispenser;

terminating the iterative build process;

removing the dispensed un-vulcanized rubber from the printing apparatus.

10. The method of claim 9, wherein the iterative build process further comprises moving the dispenser vertically.

11. The method of claim 9, wherein decreasing the viscosity of at least one of the materials includes regulating a temperature using a setpoint control loop.

12. The method of claim 9, further comprising vulcanizing the dispensed un-vulcanized rubber in an autoclave.

13. The method of claim 9, wherein the area over which the un-vulcanized rubber is dispensed is a tread component.

14. The method of claim 9, further comprising utilizing a support to buttress dispensed green rubber.

15. The method of claim 9, further comprising monitoring the amount of un-vulcanized rubber in the printing apparatus and generating an alert when the amount falls below or exceeds predetermined thresholds.

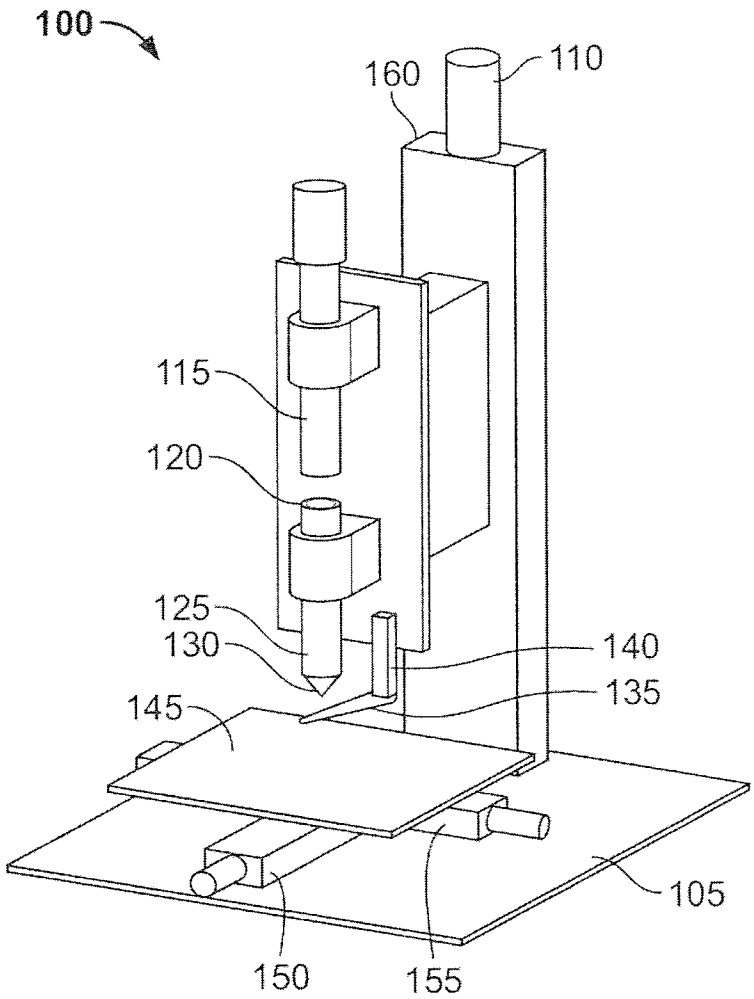


FIG. 1

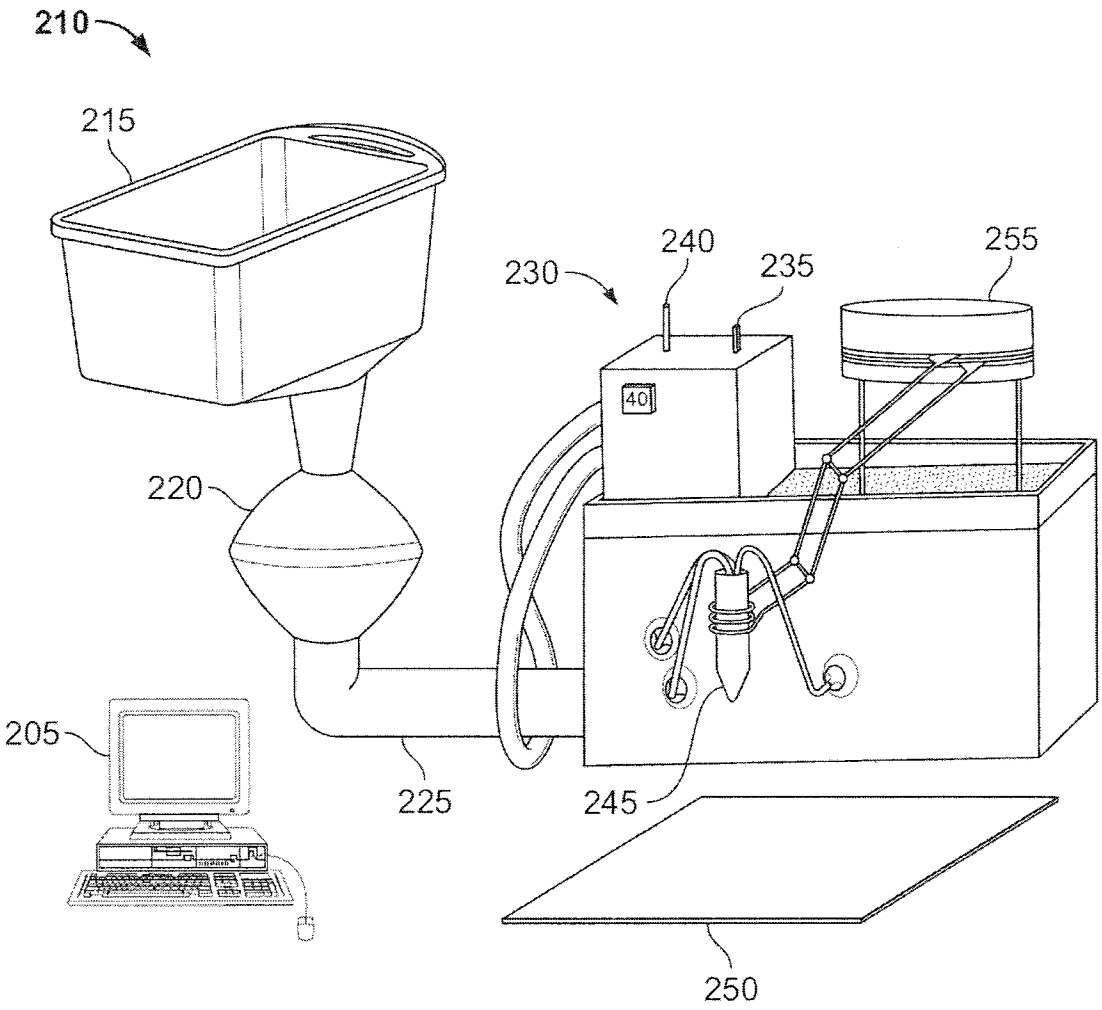


FIG. 2

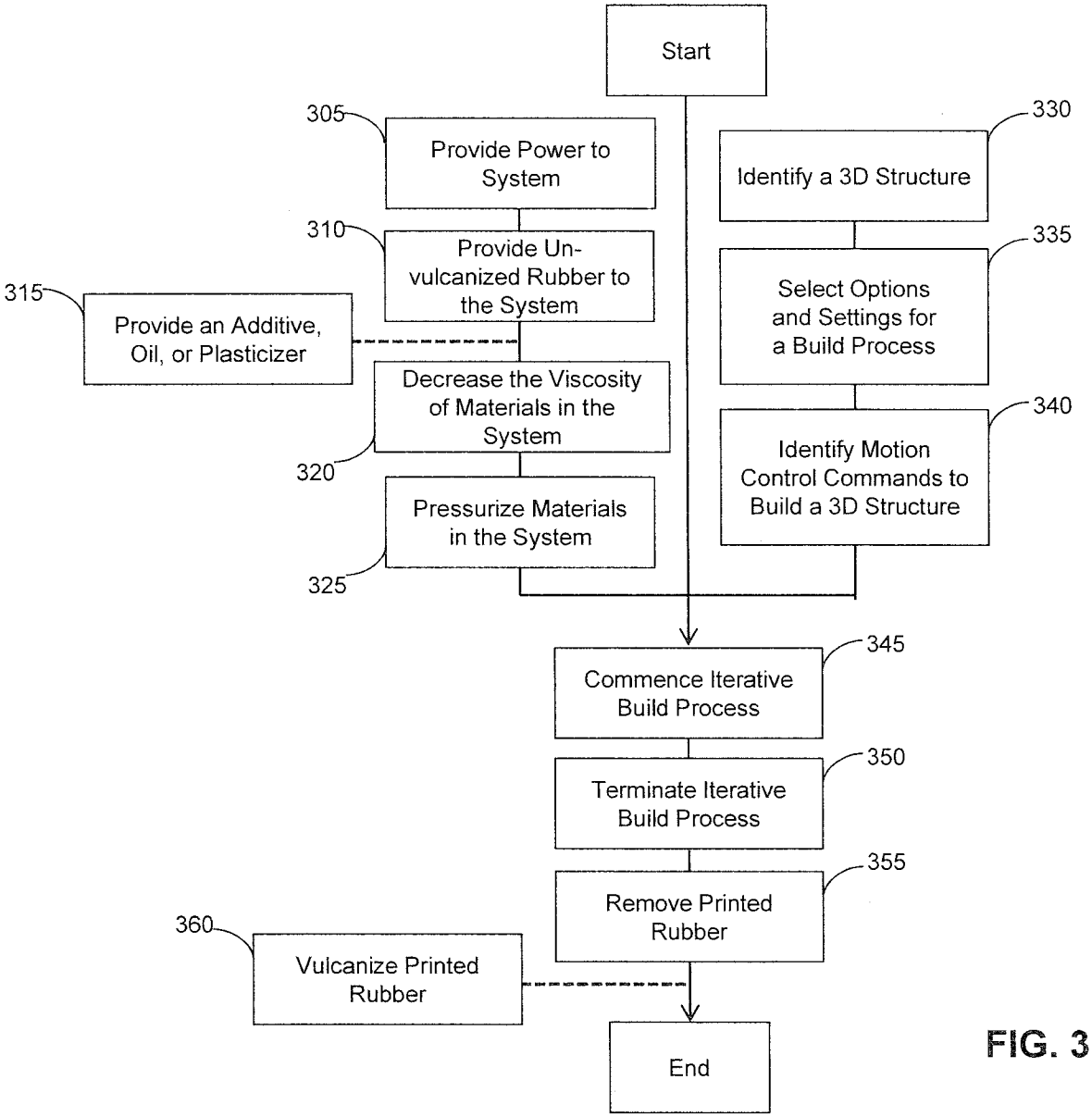

Start
305
Provide Power to System
310
Provide Un-vulcanized Rubber to the System
315
Provide an Additive, Oil, or Plasticizer
Decrease the Viscosity of Materials in the System
320
Pressurize Materials in the System
325
330
Identify a 3D Structure
335
Select Options and Settings for a Build Process
340
Identify Motion Control Commands to Build a 3D Structure
345
Commence Iterative Build Process
350
Terminate Iterative Build Process
355
Remove Printed Rubber
360
Vulcanize Printed Rubber
End

FIG. 3

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2015/057744

A. CLASSIFICATION OF SUBJECT MATTER

B29C 67/00(2006.01)i, B33Y 30/00(2015.01)i, B33Y 40/00(2015.01)i

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
B29C 67/00; B29D 30/72; G06F 15/46; B29C 45/76; B60C 13/00; A61C 13/20; B33Y 30/00; B33Y 40/00

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
Korean utility models and applications for utility models
Japanese utility models and applications for utility models

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
eKOMPASS(KIPO internal) & keywords: additively manufacturing, un-vulcanized rubber, green, heat, regulator, propulsion, nozzle, actuator, blade

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5303141 A (BATCHELDER, JOHN S. et al.) 12 April 1994 See abstract; column 4, line 36-column 8, line 28 and column 16, lines 1-15; figures 1A-6A and 7.	1,4,5,7,9-12,14,15
Y		2,3,6,8,13
Y	US 2014-0328963 A1 (MARKFORGED, INC.) 06 November 2014 See abstract; paragraphs [0093] and [0170]; figures 1A and 15B-16.	2
Y	US 5121329 A (CRUMP, S. SCOTT) 09 June 1992 See abstract; column 14, line 60-column 15, line 44; figures 1, 5 and 10.	3
Y	US 2014-0284832 A1 (NOVIKOV, PETR et al.) 25 September 2014 See abstract; paragraphs [0065]-[0067]; figure 1.	6
Y	US 2013-0108726 A1 (UCKELMANN, INGO et al.) 02 May 2013 See abstract; paragraphs [0190] and [0196]; figure 2.	8
Y	US 2006-0032569 A1 (ZIMMER, RENE JEAN et al.) 16 February 2006 See abstract; paragraphs [0018], [0022], [0037] and [0050]-[0052]; figure 1.	13
A	US 2007-0228590 A1 (LABOSSIERE, JOSEPH E. et al.) 04 October 2007 See abstract; paragraphs [0016]-[0031]; figures 1-3.	1-15

☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.

* Special categories of cited documents:
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"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents,such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
27 January 2016 (27.01.2016)	**03 February 2016 (03.02.2016)**

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INTERNATIONAL SEARCH REPORT

Information on patent family members

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PCT/US2015/057744

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