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RELIABLY MAKING MONOLITHIC INGOTS OF DIFFICULT TO CAST ALUMINUM ALLOYS USING DIRECT CHILL CASTING

BACKGROUND

[0001] Several techniques may be used for making monolithic ingots. For example, monolithic ingots may be cast using direct chill (DC) casting. Certain metals or alloys may, however, not be suitable for casting directly as monolithic ingots using DC casting techniques. For example, some metals or alloys may spontaneously rupture or undergo substantial damage during casting as a monolithic ingot.

BRIEF DESCRIPTION OF THE FIGURES

[0002] FIG. 1 provides an illustration of direct chill casting a composite ingot.

[0003] FIG. 2A, FIG. 2B, and FIG. 2C provides schematic illustration of composite ingots and FIG. 2D provides a schematic illustration of a monolithic ingot.

[0004] FIG. 3A and FIG. 3B provide schematic illustrations of scalping a composite ingot.

[0005] FIG. 4 provides a schematic overview of making and processing a monolithic ingot to make an aluminum alloy product.

DETAILED DESCRIPTION

[0006] Described herein are monolithic aluminum alloy ingots, methods of making and using monolithic aluminum alloy ingots, and products formed from monolithic aluminum alloy ingots. The disclosed monolithic aluminum alloy ingots include aluminum alloys and alloys that are difficult to directly cast as monolithic ingots using direct chill (DC) casting techniques, such as aluminum alloys and alloys that have high ductile-to-brittle transition temperatures (e.g., greater than or about 200 °C or up to about 400 °C), aluminum alloys and alloys that are susceptible to hot-tearing during casting, and aluminum alloys and alloys that can undergo brittle fracture events during casting.

[0007] As examples, certain alloys may be difficult to cast as monolithic ingots because of internal stresses that develop during casting, due to thermal contraction that occurs during cooling of the ingot by application of cooling water directly on a surface of the ingot. In some

cases, a monolithic brittle aluminum alloy ingot directly cast using a DC casting technique may spontaneously undergo catastrophic fracture and rupture upon a portion of the ingot cooling to or below the ductile-to-brittle transition temperature, resulting in damage, safety hazards, reduced recovery of cast products, and fabrication downtime to allow for cleanup, recovery, and repair of damaged components and materials. Hot-tearing may similarly occur for some aluminum alloys cast directly using DC casting, which may result in similar safety and cleanup issues and low recovery. Techniques described herein provide for ways to reliably obtain monolithic aluminum alloy ingots of such aluminum alloys and alloys that may be difficult to directly cast using DC casting techniques.

[0008] The disclosed techniques employ a DC casting technique in which a difficult to cast aluminum alloy and a protective aluminum alloy are co-cast to form a composite ingot. The difficult to cast aluminum alloy is cast in the composite ingot as a core structure, with the protective aluminum alloy cast as a clad layer. Examples of techniques for co-casting different aluminum alloys to form a composite ingot with a core/clad structure are described, for example, in U.S. Patent Nos. 7,748,434 and 8,927,113. The techniques described herein may also employ a process where the composite ingot is scalped to remove the clad layer in order to generate a monolithic ingot comprising the difficult to cast aluminum alloy.

[0009] It will be appreciated that techniques for co-casting different aluminum alloys to form a composite ingot with a core/clad structure introduce significant complexities, difficulties, and costs as compared to direct chill casting of a monolithic ingot. For example, additional and more complex processing and equipment are required, including additional furnaces, additional molten aluminum alloy handling equipment, more complex casting equipment, etc. In some cases, multiple clad layers may be utilized, further multiplying the complexities and other costs.

[0010] The process of scalping a clad layer from a composite ingot also introduces additional complexities, time, and equipment requirements as compared to direct chill casting of a monolithic ingot. For example, scalping machinery is needed, and machinery for moving, turning, or rotating the composite ingot may be needed, depending on the scalping configuration. The scalping process also takes time, resulting in reduced production throughput. Again, when multiple clad layers are used, the costs associated with scalping are multiplied.

[0011] Moreover, scalping of a clad layer from a composite ingot also results in considerably higher energy usage and necessary disposal or recycling of scalped materials. For example, the

heat requirements of an additional furnace needed to melt the aluminum alloy for the clad layer are significant. Since the aluminum alloy from the clad layer is scalped during the process of forming a monolithic ingot from a composite ingot, the energy required to heat and prepare the clad layer may be considered as wasted. Increasing energy usage and wasting energy is undesirable in aluminum alloy and alloy ingot casting processes, and may generally make such processes impractical. Scalping may also generate additional excess material to be disposed of or recycled in the form of the scalped clad layer, and the process of recycling or disposal may add other complexities and energy usage requirements. In some cases, the scalped material may include a portion of the core aluminum alloy, and so recycling of the scalped material may be complicated by having to deal with two different alloy compositions in the scalped material.

[0012] The complexities and additional energy and heat requirements all point to the unfavorability of the disclosed techniques for making a monolithic aluminum alloy ingot by first casting a composite ingot followed by scalping a clad layer. Furthermore, techniques for co-casting of a composite ingot, such as described in U.S. Patent Nos. 7,748,434 and 8,927,113, are focused on how to add material as a clad layer on an outside of an ingot. However, for particular aluminum alloys and alloys, the disclosed techniques are advantageous, as they allow creation of monolithic ingots, such as monolithic ingots of brittle aluminum alloys and alloys and aluminum alloys and alloys subject to hot-tearing and spontaneous rupture, in a way that is safe and reliable and that minimizes or reduces problems associated with directly casting monolithic ingots of brittle aluminum alloys and alloys. The recovery of monolithic aluminum alloy ingots in this way can be higher than using other methods (which may be more complex or less complex) for forming aluminum alloy ingots of a difficult to cast aluminum alloy. In some cases, monolithic aluminum alloy ingots formed according to the present disclosure can be significantly larger than formed using other methods, which again may be more complex or less complex than the presently disclosed methods.

Definitions and Descriptions:

[0013] In this description, reference is made to alloys identified by AA numbers and other related designations, such as “series” or “7xxx.” For an understanding of the number designation system most commonly used in naming and identifying aluminum and its alloys, see “International Alloy Designations and Chemical Composition Limits for Wrought Aluminum and Wrought Aluminum Alloys” or “Registration Record of Aluminum Association Alloy

Designations and Chemical Compositions Limits for Aluminum Alloys in the Form of Castings and Ingot,” both published by The Aluminum Association.

[0014] As used herein, a plate generally has a thickness of greater than about 15 mm. For example, a plate may refer to an aluminum product having a thickness of greater than about 15 mm, greater than about 20 mm, greater than about 25 mm, greater than about 30 mm, greater than about 35 mm, greater than about 40 mm, greater than about 45 mm, greater than about 50 mm, or greater than about 100 mm.

[0015] As used herein, a shate (also referred to as a sheet plate) generally has a thickness of from about 4 mm to about 15 mm. For example, a shate may have a thickness of about 4 mm, about 5 mm, about 6 mm, about 7 mm, about 8 mm, about 9 mm, about 10 mm, about 11 mm, about 12 mm, about 13 mm, about 14 mm, or about 15 mm.

[0016] As used herein, a sheet generally refers to an aluminum product having a thickness of less than about 4 mm. For example, a sheet may have a thickness of less than about 4 mm, less than about 3 mm, less than about 2 mm, less than about 1 mm, less than about 0.5 mm, or less than about 0.3 mm (e.g., about 0.2 mm).

[0017] “Ductile-brittle transition temperature” refers to a temperature at which the fracture energy of a metal alloy falls below a predetermined value, such as determined according to an impact test (see, e.g., ASTM A370, hereby incorporated by reference). In some cases, a ductile-brittle transition temperature refers to temperature at which a change in ductility of a metal alloy is observed, below which the metal alloy exhibits a more brittle character and above which the metal alloy exhibits a more ductile character. For example, at temperatures below the metal alloy’s ductile-brittle transition temperature an impact of a particular or standard magnitude may cause the metal alloy to fracture, while at temperatures above the metal alloy’s ductile-brittle transition temperature an impact of the particular or standard magnitude may instead result in deformation of the metal alloy rather than fracture. In some cases, during casting of a metal alloy ingot, the surface of the ingot may be exposed to cooling water while the center of the ingot may still remain at elevated temperature. Stresses and strains may occur within the ingot due to the non-uniform temperature profile of the ingot and temperature-dependent thermal expansion/contraction. If the ductile-brittle transition temperature of the metal alloy is too high, the ingot may spontaneously rupture from the stresses and strains that develop during cooling of the ingot.

[0018] As used herein, terms such as “cast aluminum alloy product,” “cast product,” “cast aluminum alloy product,” and the like are interchangeable and refer to a product produced by direct chill casting (including direct chill co-casting) or semi-continuous casting, continuous casting (including, for example, by use of a twin belt caster, a twin roll caster, a block caster, or any other continuous caster), electromagnetic casting, hot top casting, or any other casting method.

[0019] All ranges disclosed herein are to be understood to encompass any and all subranges subsumed therein. For example, a stated range of “1 to 10” should be considered to include any and all subranges between (and inclusive of) the minimum value of 1 and the maximum value of 10; that is, all subranges beginning with a minimum value of 1 or more, e.g. 1 to 6.1, and ending with a maximum value of 10 or less, e.g., 5.5 to 10. Unless stated otherwise, the expression “up to” when referring to the compositional amount of an element means that element is optional and includes a zero percent composition of that particular element. Unless stated otherwise, all compositional percentages are in weight percent (wt. %).

[0020] As used herein, the meaning of “a,” “an,” and “the” includes singular and plural references unless the context clearly dictates otherwise.

[0021] In the below description, aluminum alloys and aluminum alloy products may be described in terms of their elemental composition in weight percent (wt. %). Incidental elements, such as grain refiners and deoxidizers, or other additives may be present and may add other characteristics on their own without departing from or significantly altering the alloy described herein or the characteristics of the alloy described herein. A solute may represent the component of an alloy that is different from a primary element component. For example, in aluminum alloys, components other than aluminum (e.g., Mg, Si, Zn, Fe, etc.) may be considered solute components.

[0022] Unavoidable impurities, including materials or elements, may be present in the alloy in minor amounts due to inherent properties of aluminum or leaching from contact with processing equipment. Some impurities typically found in aluminum include iron and silicon. The alloy, as described, may contain no more than about 0.25 wt. % of any element besides the alloying elements, incidental elements, and unavoidable impurities.

Methods of Using the Disclosed Aluminum Alloys and Aluminum Alloy Products

[0023] The aluminum alloys and aluminum alloy products described herein, such as monolithic aluminum alloy ingots, and rolled aluminum alloy products, can be used in automotive applications and other transportation applications, including aircraft and railway applications. For example, disclosed aluminum alloy products can be used to prepare automotive structural parts, such as bumpers, side beams, roof beams, cross beams, pillar reinforcements (e.g., A-pillars, B-pillars, and C-pillars), inner panels, outer panels, side panels, inner hoods, outer hoods, or trunk lid panels. The aluminum alloy products and methods described herein can also be used in aircraft or railway vehicle applications, to prepare, for example, external and internal panels.

[0024] The aluminum alloy products and methods described herein can also be used in electronics applications. For example, the aluminum alloy products and methods described herein can be used to prepare housings for electronic devices, including mobile phones and tablet computers. In some examples, the aluminum alloy products can be used to prepare housings for the outer casing of mobile phones (e.g., smart phones), tablet bottom chassis, and other portable electronics.

Methods of Producing the Alloys and Alloy Products

[0025] The aluminum alloys and aluminum alloy products described herein can be cast using any suitable casting method. As a non-limiting example, the casting process can include a Direct Chill (DC) casting process.

[0026] A clad layer as described herein can be attached to a core layer as described herein to form a clad product by any suitable means. For example, a clad layer can be attached to a core layer by direct chill co-casting (i.e., fusion casting) as described in, for example, U.S. Patent Nos. 7,472,740, 7,748,434, and 8,927,113. The initial dimensions and final dimensions of the clad aluminum alloy products described herein can be determined by the desired properties of the overall final product.

[0027] The co-casting process can be carried out in different manners and the co-cast ingot or other cast product can be processed by any suitable means. Optionally, the processing steps can be used to prepare sheets. Such processing steps include, but are not limited to, homogenization, hot rolling, cold rolling, solution heat treatment, and an optional pre-aging step.

Separate rolling steps can optionally be separated by other processing steps, including, for example, annealing steps, cleaning steps, heating steps, cooling steps, and the like.

[0028] FIG. 1 provides a schematic illustration of direct chill co-casting of different molten aluminum alloys 105 and 115 to form a composite ingot. It will be appreciated that reference to aluminum alloys herein optionally may be substituted with other alloys, such as steel, magnesium alloys, copper alloys, or the like. A direct chill co-casting technique may be useful for forming a core-clad or multilayer structure comprising different aluminum alloys. As illustrated, molten aluminum alloys 105 and 115 are cast in a vertical casting arrangement where they are allowed to contact one another in a molten and/or partially molten configuration. Such a technique may be useful for forming a composite ingot comprising aluminum alloys 110 and 120, which can then undergo further processing.

[0029] Molten aluminum alloys 105 and 115 (and consequently aluminum alloys 110 and 120) are typically different aluminum alloys. For example, molten aluminum alloy 115/aluminum alloy 120 may correspond to an alloy that is brittle upon cooling to a temperature greater than or about 200 °C or greater than or about 300 °C. Optionally, molten aluminum alloy 115/aluminum alloy 120 may correspond to an alloy that has a ductile-to-brittle transition temperature of greater than or about 200 °C, greater than or about 300 °C, or greater than or about 400 °C, such as a ductile-to-brittle transition temperature of about 200 °C, about 205 °C, about 210 °C, about 215 °C, about 220 °C, about 225 °C, about 230 °C, about 235 °C, about 240 °C, about 245 °C, about 250 °C, about 255 °C, about 260 °C, about 265 °C, about 270 °C, about 275 °C, about 280 °C, about 285 °C, about 290 °C, about 295 °C, about 300 °C, about 305 °C, about 310 °C, about 315 °C, about 320 °C, about 325 °C, about 330 °C, about 335 °C, about 340 °C, about 345 °C, about 350 °C, about 355 °C, about 360 °C, about 370 °C, about 380 °C, about 385 °C, about 390 °C, about 395 °C, or about 400 °C. Optionally, aluminum alloy 115/aluminum alloy 120 may correspond to a high solute alloy, such as exhibiting a solute concentration between about 6% and about 18%, by weight. For example, aluminum alloy 115/aluminum alloy 120 may have a solute concentration of about 6%, about 6.5%, about 7%, about 7.5%, about 8%, about 8.5%, about 9%, about 9.5%, about 10%, about 10.5%, about 11%, about 11.5%, about 12%, about 12.5%, about 13%, about 13.5%, about 14%, about 14.5%, about 15%, about 15.5%, about 16%, about 16.5%, about 17%, about 17.5%, or about 18%, by weight. Optionally, molten aluminum alloy 115/aluminum alloy 120 may correspond to an aluminum

alloy with a high copper composition or a high magnesium composition, such as in certain 2xxx series aluminum alloys and certain 5xxx series aluminum alloys.

[0030] Molten aluminum alloy 105/aluminum alloy 110, on the other hand, may correspond to a different alloy than molten aluminum alloy 115/aluminum alloy 120. For example, aluminum alloy 110 may optionally be more ductile than aluminum alloy 120. In this way, molten aluminum alloy 105/aluminum alloy 120 may function as a buffer layer between molten aluminum alloy 115/aluminum alloy 120 and cooling water 130 during casting. For example, being more ductile, molten aluminum alloy 105/aluminum alloy 120 may not undergo spontaneous fracture upon exposure to cooling water 130 or may not undergo hot-tearing during casting. Molten aluminum alloy 115/aluminum alloy 120, on the other hand, may be subject to spontaneous fracture if directly exposed to cooling water 130 or may be subject to hot-tearing during casting.

[0031] To achieve such buffering, molten aluminum alloy 105/aluminum alloy 120 may have a heat transfer coefficient between about 100 W/m·K and about 250 W/m·K, such as about 105 W/m·K, about 110 W/m·K, about 115 W/m·K, about 120 W/m·K, about 125 W/m·K, about 130 W/m·K, about 135 W/m·K, about 140 W/m·K, about 145 W/m·K, about 150 W/m·K, about 155 W/m·K, about 160 W/m·K, about 165 W/m·K, about 170 W/m·K, about 175 W/m·K, about 180 W/m·K, about 185 W/m·K, about 190 W/m·K, about 195 W/m·K, about 200 W/m·K, about 205 W/m·K, about 210 W/m·K, about 215 W/m·K, about 220 W/m·K, about 225 W/m·K, about 230 W/m·K, about 235 W/m·K, about 240 W/m·K, about 245 W/m·K, or about 250 W/m·K. Aluminum alloy 120 may have a thickness corresponding to between 5-15% of the total thickness of the ingot. For example, aluminum alloy 120 have a percent thickness of the total thickness of the ingot of about 5%, about 5.5%, about 6%, about 6.5%, about 7%, about 7.5%, about 8%, about 8.5%, about 9%, about 9.5%, about 10%, about 10.5%, about 11%, about 11.5%, about 12%, about 12.5%, about 13%, about 13.5%, about 14%, about 14.5%, or about 15%.

[0032] Although molten aluminum alloy 105/aluminum alloy 120 are shown as symmetric about molten aluminum alloy 115/aluminum alloy 120 in FIG. 1, it will be understood that the depiction of FIG. 1 is merely exemplary and that other co-casting configurations are possible and included within the present disclosure, including where each of molten aluminum alloy 105/aluminum alloy 120 on the left/right of molten aluminum alloy 115/aluminum alloy 120

have different thicknesses and/or have different compositions. In some cases, FIG. 1 may represent a cylindrical ingot or a rectangular or other shaped ingot where aluminum alloy 110 forms a continuous clad layer around aluminum alloy 120, which corresponds to a core of the ingot.

[0033] Turning next to FIG. 2A, a composite ingot 200 is schematically illustrated. Composite ingot 200 includes first aluminum alloy 205 and second aluminum alloy 210 in a “sandwich” configuration with third aluminum alloy 215. First aluminum alloy 205 and third aluminum alloy 215 correspond to a clad layers and second aluminum alloy 210 corresponds to a core formed in a DC co-casting process, such as depicted in FIG. 1. As illustrated, second aluminum alloy 210 has not undergone spontaneous rupturing or fracturing during the casting process, and composite ingot 200 is structurally sound but does include both core and clad layers. As noted above first aluminum alloy 205 and third aluminum alloy 215 may have the same or different compositions. FIG. 2B illustrates a configuration where composite ingot 200 has a cylindrical shape with a continuous clad layer on an outer surface. FIG. 2C illustrates a configuration where composite ingot 200 has a rectangular or square cross-sectional shape with a continuous clad layer on an outer surface. The configurations depicted in FIG. 2B and 2C may be advantageous, as a complete shell of clad layer may serve to protect and support the core and serve as a buffer for removal of heat from the core during the casting process.

[0034] To form a monolithic ingot 220, as depicted in FIG. 2D, comprising, consisting of, or consisting essentially of second aluminum alloy 210, a process of removing the clad layers of first aluminum alloy 205 (and third aluminum alloy 215, if present) from composite ingot 200 may be used, such as a scalping or other machining process.

[0035] FIG. 3A and FIG. 3B provide schematic illustrations of example scalping processes useful with the techniques disclosed herein for removing a clad layer of first aluminum alloy 305 from a composite ingot 300. Depending on the casting configuration and the thickness, length, width, and composition of the clad layer of first aluminum alloy 305 and composite ingot 300, different scalping techniques may be utilized. In FIG. 3A, scalping of composite ingot 300 involves a machining process where composite ingot 300 is moved relative to a machining tool 330 to remove clad layer of first aluminum alloy 305 as an at least partially continuous layer. Machining tool 330 is depicted as a band saw type device. FIG. 3B provides a schematic illustration of a different method of scalping composite ingot. In FIG. 3B, machining tool 330 is

depicted as a mill type device, where a rotating cutting tool is used to chip and remove clad layer of first aluminum alloy 305, such as using one or more milling operations/passes.

[0036] As depicted, composite ingot 300 include two separate clad layers of first aluminum alloy 305. To remove both clad layers of first aluminum alloy 305 and form a monolithic ingot of just second aluminum alloy 310, it may be useful to rotate composite ingot 300 after a first machining process. However, in some configurations, multiple machining tools 330 may be used simultaneously and/or sequentially to remove multiple clad layers of first aluminum alloy 305, such as when composite ingot 300 is oriented in a configuration where clad layers of first aluminum alloy 305 are vertically arranged, rather than in the horizontal configuration depicted in FIGs. 3A and 3B.

[0037] It will be appreciated that other components may be useful or required for removing clad layer of first aluminum alloy 305 using the configuration depicted in FIGs. 3A and 3B, such as lubricating/cooling fluids, chip collection mechanisms, etc., but these are not shown in the figures so as not to obscure other details. Other machining techniques and operations beyond those illustrated are also possible. For example, for machining some ingots, such as the cylindrical ingot depicted in FIG. 2B, a lathe or other device where the ingot is rotated while the machine tool is held stationary may be used.

[0038] It will be appreciated that materials properties may dictate the useful scalping technique, as some aluminum alloys may be more suitably machined using particular techniques than others. Alternatively, the available scalping equipment may be used to dictate which aluminum alloys may be used for clad layer. In some cases, however, the combination of materials properties of the aluminum alloy used for the clad layer and the core may be evaluated to identify which aluminum alloys are suitable for the clad layer. For example, the heat transfer coefficient of the clad layer may be a useful characteristic to consider, as it may be desirable to control the rate of heat transfer from the core to the clad and cooling water to prevent fracture and/or damage to the core during the casting process. Ductility of the clad layer may also play a part in the selection of an appropriate clad layer aluminum alloy, as it may be beneficial to select a clad layer that has a particular ductility to accommodate stresses that may develop within the core to provide a protective effect against fracture, cracking, or other damage to the core during the casting process. Thermal expansion characteristics may also play a part in the selection of appropriate alloys for the clad layers, as it may be beneficial to use an alloy in the clad layer that

has the same or different thermal expansion characteristics as the alloy of the core to accommodate thermal contraction of the core and provide a protective effect against fracturing, cracking, or other damage to the core during cooling that takes place while or after casting.

[0039] In some cases, a composite ingot may be stable during casting, but can rupture before or during scalping, due to residual stress within the composite ingot. Optionally, a composite ingot may be subjected to a variety of processing steps after casting and prior to scalping to relieve, limit, or otherwise reduce stress within the composite ingot. For example, the composite ingot may be optionally preheated and/or homogenized after removal from the casting pit and prior to scalping. Example preheating and homogenization temperatures may range from about 325 °C to about 520 °C, such as from about 325 °C to about 450 °C or from about 325 °C to about 400 °C. Preheating and/or homogenization of a composite ingot to temperatures within these ranges may be useful for limiting intermetallic precipitation.

[0040] Once prepared, a monolithic ingot can be processed by any suitable means. FIG. 4 provides a schematic overview of subjecting a monolithic ingot 400, prepared according to a composite ingot casting and scalping process 405, to additional nonlimiting processing steps including a homogenization step 410, a hot rolling step 415, and a cold rolling step 420. Other example processing steps include, but are not limited to, a solution heat treatment step, a preheating step between the homogenization step 410 and the hot rolling step 415, and a pre-aging step. In some cases, scalping process 405 can optionally be the process described in FIGs. 3A-3D.

[0041] In a homogenization step 410, a product, such as monolithic ingot 400, is heated to a temperature ranging from about 400 °C to about 500 °C. For example, the product can be heated to a temperature of about 400 °C, about 410 °C, about 420 °C, about 430 °C, about 440 °C, about 450 °C, about 460 °C, about 470 °C, about 480 °C, about 490 °C, or about 500 °C. The product is then allowed to soak (i.e., held at the indicated temperature) for a period of time to form a homogenized product. In some examples, the total time for the homogenization step 410, including the heating and soaking phases, can be up to 24 hours. For example, the product can be heated up to 500 °C and soaked, for a total time of up to 18 hours for the homogenization step 410. Optionally, the product can be heated to below 490 °C and soaked, for a total time of greater than 18 hours for the homogenization step 410. In some cases, the homogenization step 410 comprises multiple processes. In some non-limiting examples, the homogenization step 410

includes heating a product to a first temperature for a first period of time followed by heating to a second temperature for a second period of time. For example, a product can be heated to about 465 °C for about 3.5 hours and then heated to about 480 °C for about 6 hours.

[0042] Following a homogenization step 410, a hot rolling step 415 can be performed. Prior to the start of hot rolling, the homogenized product can be allowed to cool to a temperature between 300 °C to 450 °C. For example, the homogenized product can be allowed to cool to a temperature of between 325 °C to 425 °C or from 350 °C to 400 °C. The homogenized product can then be hot rolled at a temperature between 300 °C to 450 °C to form a hot rolled plate, a hot rolled shate or a hot rolled sheet having a gauge between 3 mm and 200 mm (e.g., 3 mm, 4 mm, 5 mm, 6 mm, 7 mm, 8 mm, 9 mm, 10 mm, 15 mm, 20 mm, 25 mm, 30 mm, 35 mm, 40 mm, 45 mm, 50 mm, 55 mm, 60 mm, 65 mm, 70 mm, 75 mm, 80 mm, 85 mm, 90 mm, 95 mm, 100 mm, 110 mm, 120 mm, 130 mm, 140 mm, 150 mm, 160 mm, 170 mm, 180 mm, 190 mm, 200 mm, or anywhere in between). During hot rolling, temperatures and other operating parameters can be controlled so that the temperature of the hot rolled intermediate product upon exit from the hot rolling mill is no more than 470 °C, no more than 450 °C, no more than 440 °C, or no more than 430 °C.

[0043] As illustrated, the hot-rolled product can be subjected to a cold rolling step 420, using cold rolling mills to process the hot-rolled product into thinner products, such as a cold rolled sheet. The cold rolled product can have a gauge between about 0.5 to 10 mm, e.g., between about 0.7 to 6.5 mm. Optionally, the cold rolled product can have a gauge of 0.5 mm, 1.0 mm, 1.5 mm, 2.0 mm, 2.5 mm, 3.0 mm, 3.5 mm, 4.0 mm, 4.5 mm, 5.0 mm, 5.5 mm, 6.0 mm, 6.5 mm, 7.0 mm, 7.5 mm, 8.0 mm, 8.5 mm, 9.0 mm, 9.5 mm, or 10.0 mm. The cold rolling can be performed to result in a final gauge thickness that represents a gauge reduction of up to 85 % (e.g., up to 10 %, up to 20 %, up to 30 %, up to 40 %, up to 50 %, up to 60 %, up to 70 %, up to 80 %, or up to 85 % reduction) as compared to a gauge prior to the start of cold rolling.

[0044] Optionally, an interannealing step can be performed during the cold rolling step, such as where a first cold rolling process is applied, followed by an annealing process (interannealing), followed by a second cold rolling process. The interannealing step can be performed at a temperature of from about 300 °C to about 450 °C (e.g., about 310 °C, about 320 °C, about 330 °C, about 340 °C, about 350 °C, about 360 °C, about 370 °C, about 380 °C, about 390 °C, about 400 °C, about 410 °C, about 420 °C, about 430 °C, about 440 °C, or about 450

°C). In some cases, the interannealing step comprises multiple processes. In some non-limiting examples, the interannealing step includes heating the partially cold rolled product to a first temperature for a first period of time followed by heating to a second temperature for a second period of time. For example, the partially cold rolled product can be heated to about 410 °C for about 1 hour and then heated to about 330 °C for about 2 hours.

[0045] An unprocessed monolithic aluminum alloy ingot, a homogenized monolithic aluminum alloy ingot, or a rolled monolithic aluminum alloy product can optionally undergo a solution heat treatment step. The solution heat treatment step can be any suitable treatment which results in solutionizing of the soluble particles. The product, for example, can be heated to a peak metal temperature (PMT) of up to 590 °C (e.g., from 400 °C to 590 °C) and soaked for a period of time at the PMT to form a hot product. For example, the cast, homogenized, or rolled product can be soaked at 480 °C for a soak time of up to 30 minutes (e.g., 0 seconds, 60 seconds, 75 seconds, 90 seconds, 5 minutes, 10 minutes, 20 minutes, 25 minutes, or 30 minutes). After heating and soaking, the hot product is rapidly cooled at rates greater than 200 °C/s to a temperature between 500 and 200 °C to form a heat-treated product. In one example, the hot product is cooled at a quench rate of above 200 °C/second at temperatures between 450 °C and 200 °C. Optionally, the cooling rates can be faster in other cases.

[0046] Optionally, a heat-treated product can undergo a pre-aging treatment by reheating before coiling, for example. The pre-aging treatment can be performed at a temperature of from about 70 °C to about 125 °C for a period of time of up to 6 hours. For example, the pre-aging treatment can be performed at a temperature of about 70 °C, about 75 °C, about 80 °C, about 85 °C, about 90 °C, about 95 °C, about 100 °C, about 105 °C, about 110 °C, about 115 °C, about 120 °C, or about 125 °C. Optionally, the pre-aging treatment can be performed for about 30 minutes, about 1 hour, about 2 hours, about 3 hours, about 4 hours, about 5 hours, or about 6 hours. The pre-aging treatment can be carried out by passing the heat-treated product through a heating device, such as a device that emits radiant heat, convective heat, induction heat, infrared heat, or the like.

[0047] The monolithic aluminum alloy products described herein can be used to make products in the form of sheets, plates, or other suitable products. For example, plates including the products as described herein can be prepared by processing a monolithic aluminum alloy ingot in a homogenization step followed by a hot rolling step. In the hot rolling step, the

monolithic aluminum alloy product can be hot rolled to a 200 mm thick gauge or less (e.g., from about 10 mm to about 200 mm). For example, the monolithic aluminum alloy product can be hot rolled to a plate having a final gauge thickness of about 10 mm to about 175 mm, about 15 mm to about 150 mm, about 20 mm to about 125 mm, about 25 mm to about 100 mm, about 30 mm to about 75 mm, or about 35 mm to about 50 mm. In some cases, plates may be rolled into thinner metal products, such as sheets.

[0048] During the studies described in the following examples, conventional procedures were followed, unless otherwise stated.

EXAMPLE A

[0049] A composite ingot is formed by a vertical casting technique, such as illustrated in FIG. 1. The aluminum alloy used for the clad layers is a 5182 aluminum alloy. The aluminum alloy used for the core is 7075 aluminum alloy. The molten alloys are co-cast and the resultant composite ingot has a thickness of about 40 cm, with the clad being about 4 cm thick. After the ingot is cooled to ambient temperature, it is moved to a processing facility where the ingot is subjected to a scalping operation. During the scalping operation about 4.1 cm, corresponding to the clad, is removed from each clad surface by separate milling operations to form a monolithic 7075 aluminum ingot. The monolithic ingot is transferred to a rolling mill for subsequent processing.

EXAMPLE B

[0050] A composite ingot is formed by a vertical casting technique, such as illustrated in FIG. 1. The aluminum alloy used for the clad layers is a 1050 aluminum alloy. The aluminum alloy used for the core is 2024. The molten alloys are co-cast and the resultant composite ingot has a thickness of about 30 cm, with the clad being about 3 cm thick. After the ingot is cooled to ambient temperature, it is moved to a processing facility where the ingot is subjected to a scalping operation. During the scalping operation about 3 cm, corresponding to the clad, is removed from each clad surface by separate milling operations to form a monolithic 2024 aluminum ingot. The monolithic ingot is transferred to a rolling mill for subsequent processing.

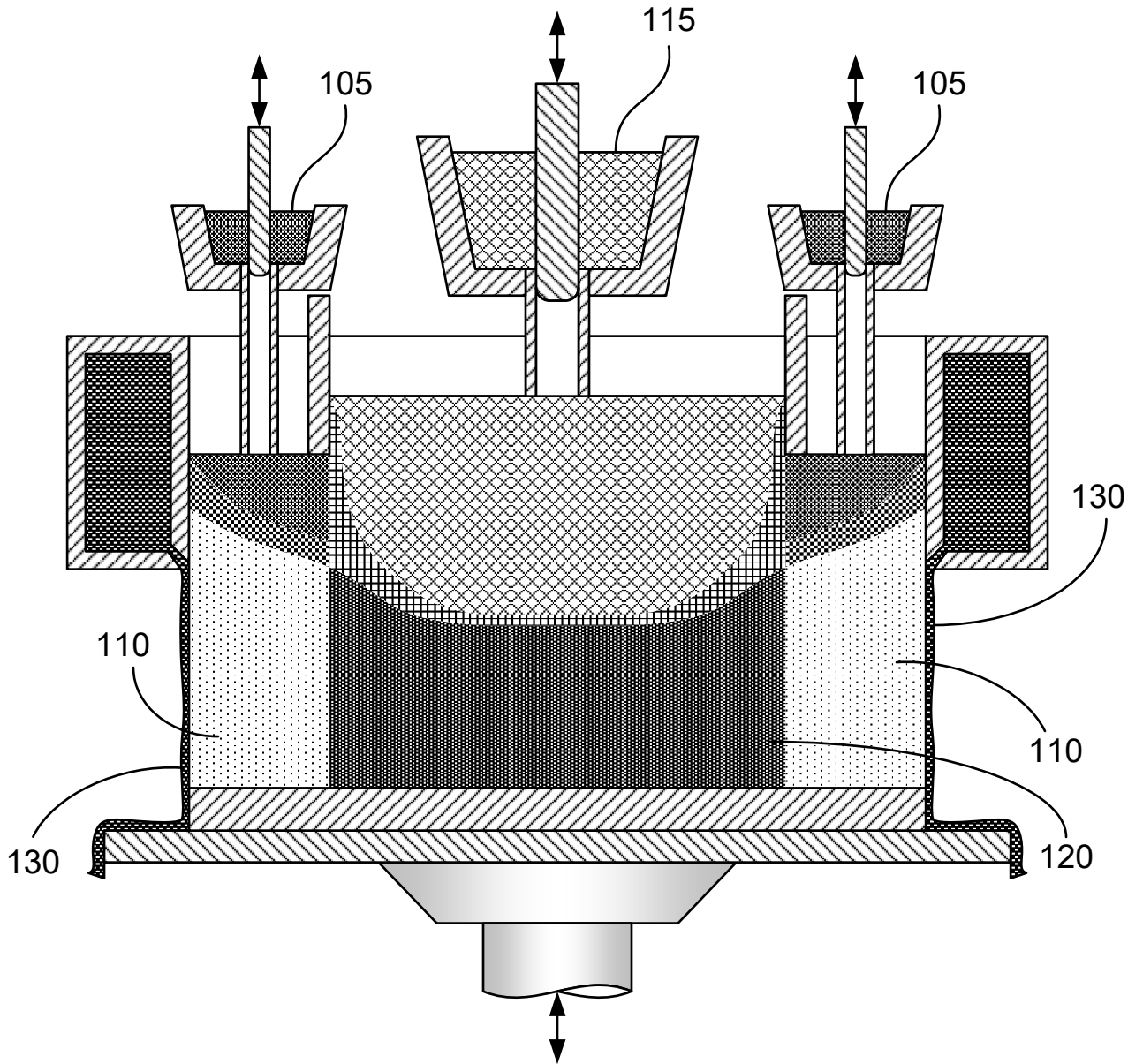


FIG. 1

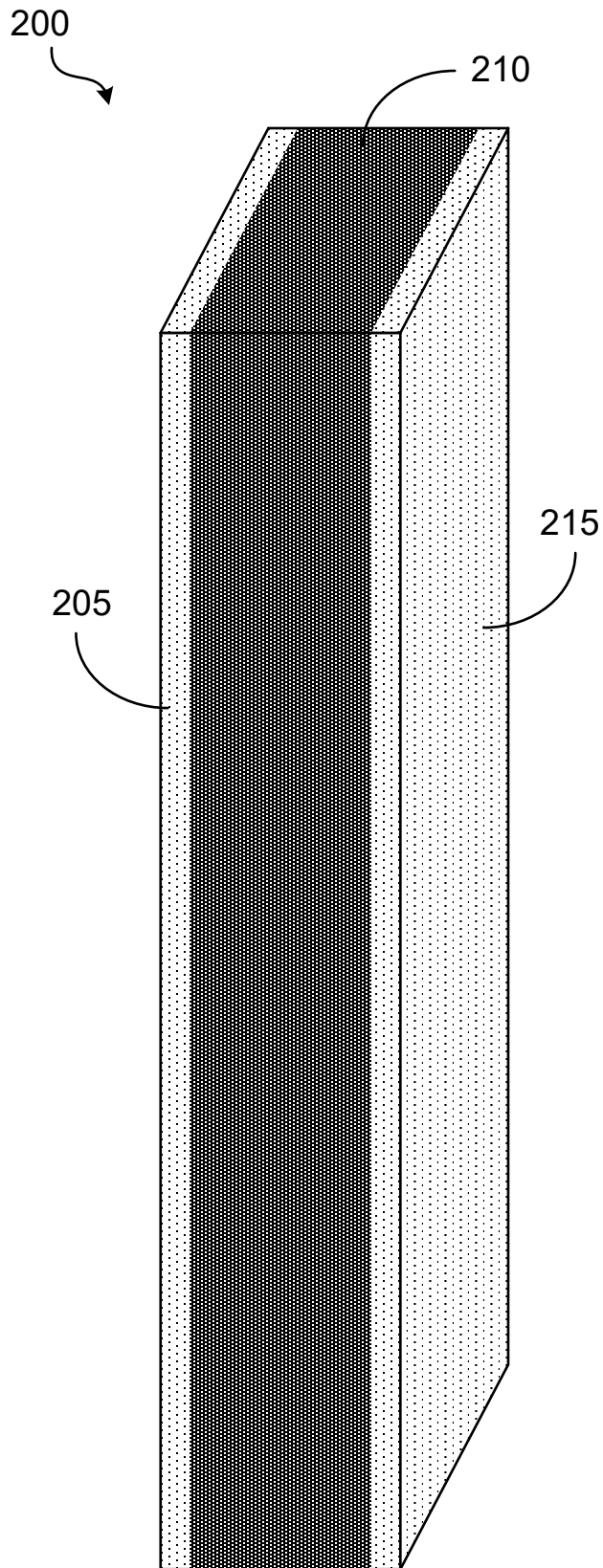


FIG. 2A

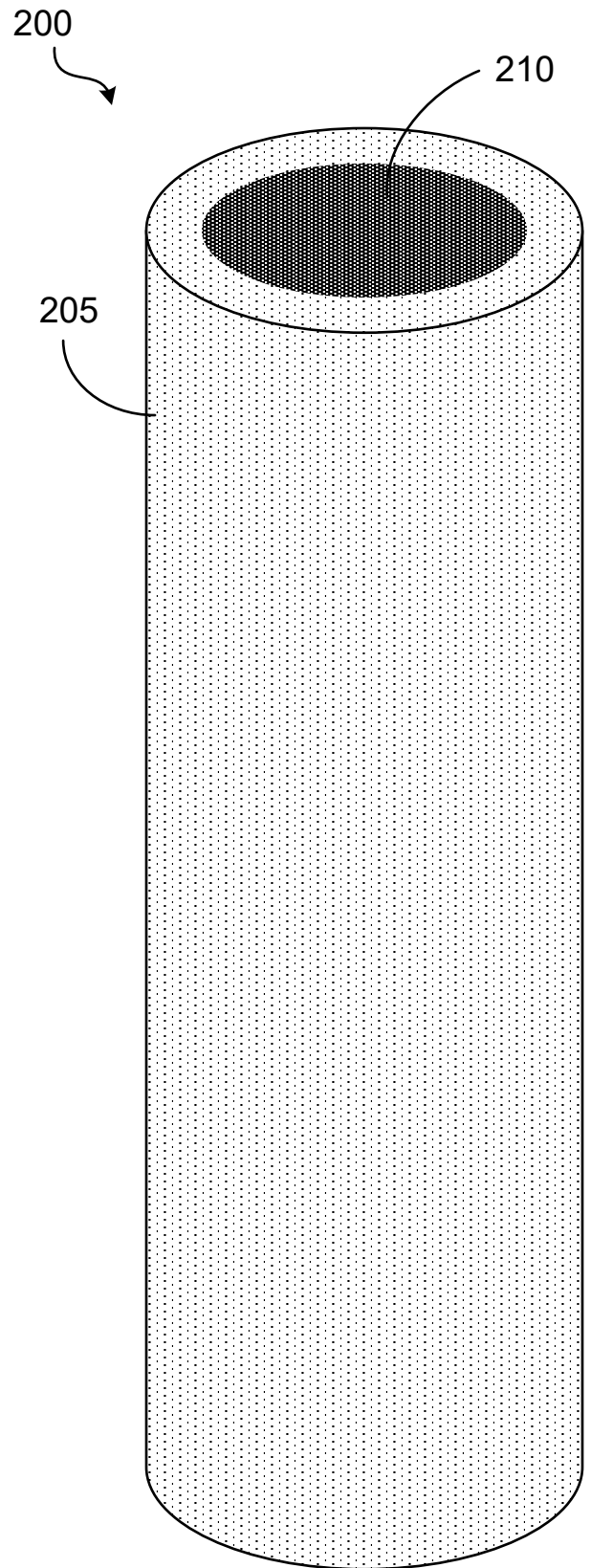


FIG. 2B

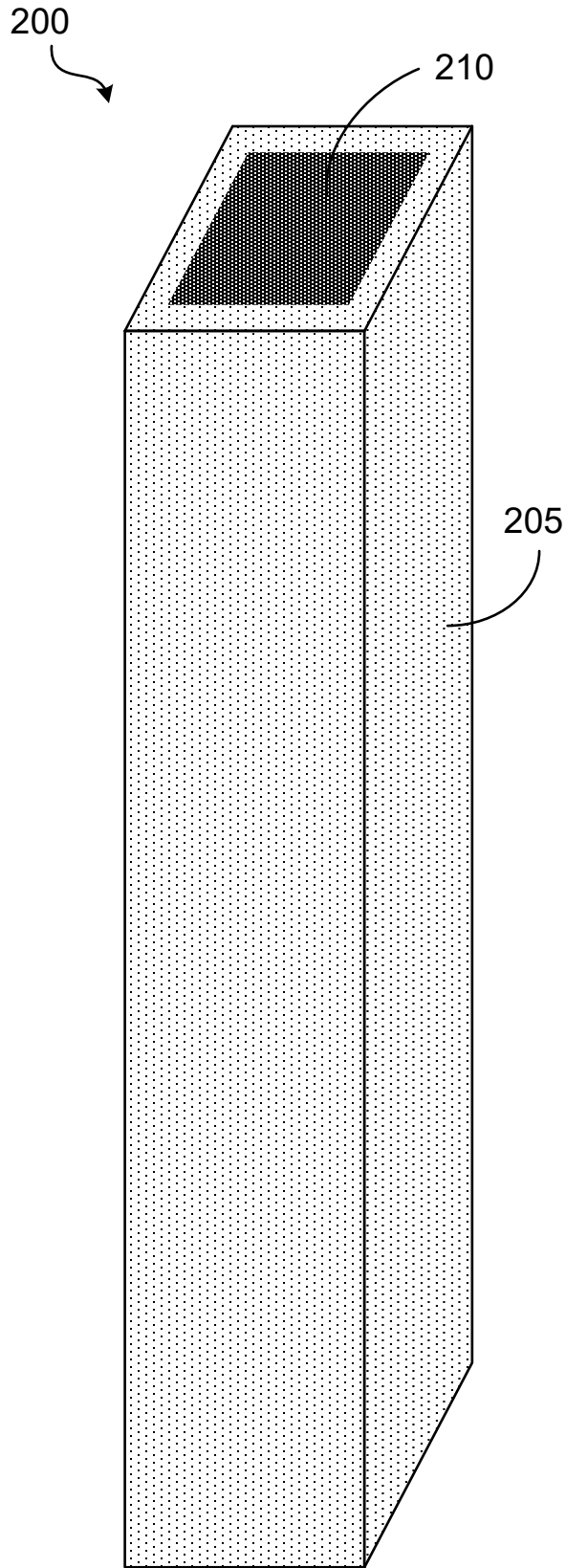


FIG. 2C

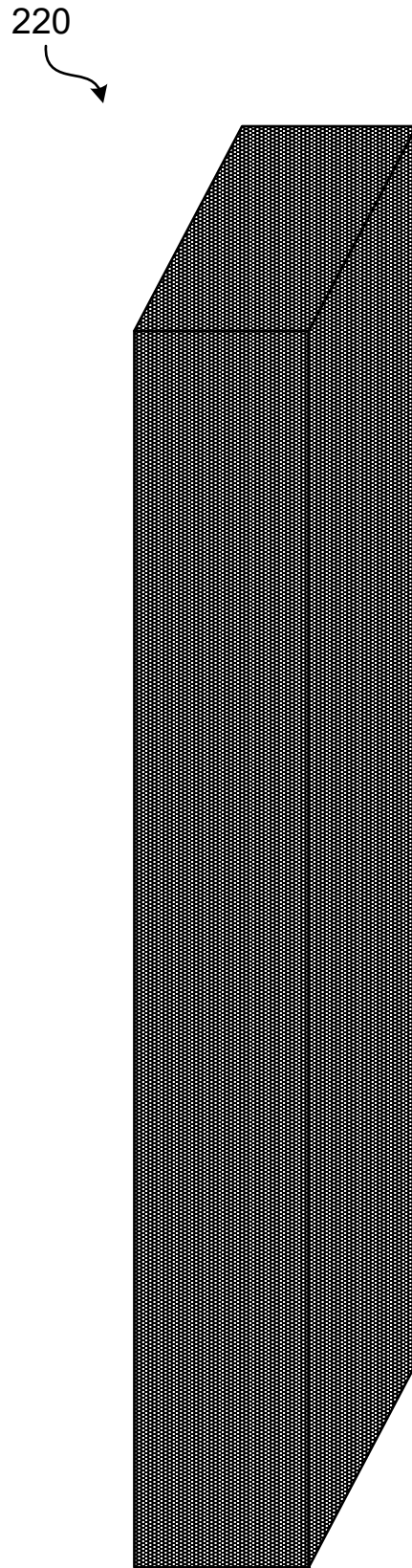


FIG. 2D

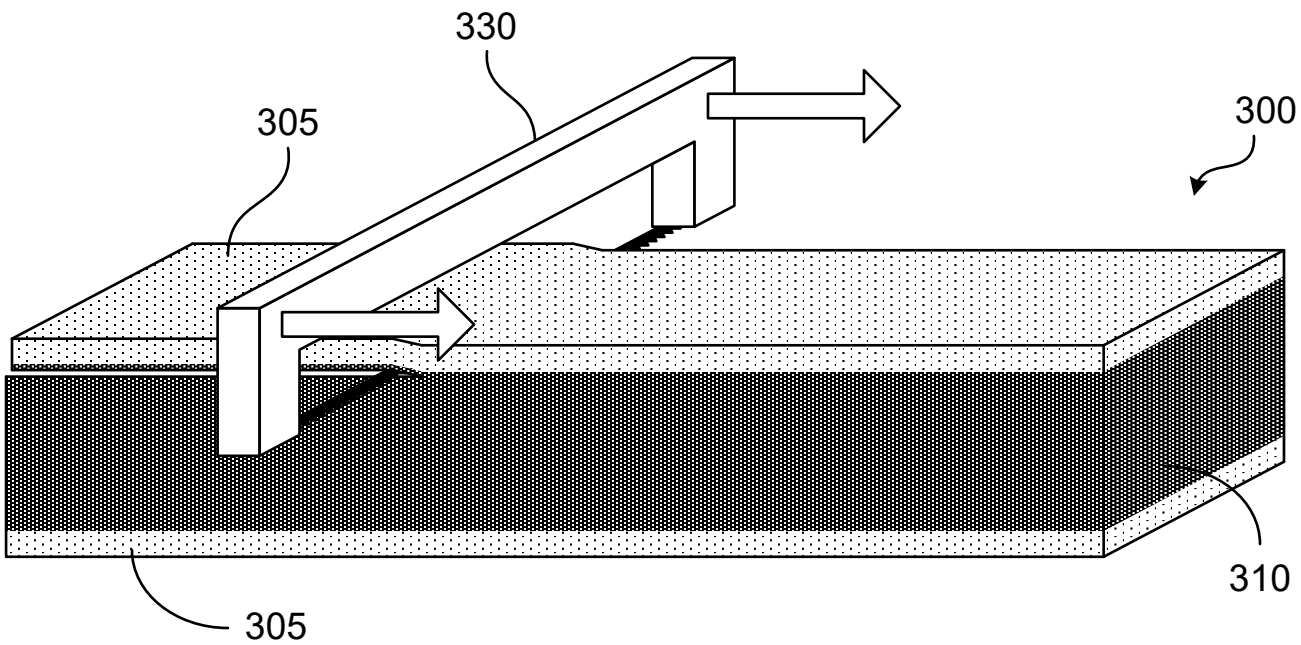


FIG. 3A

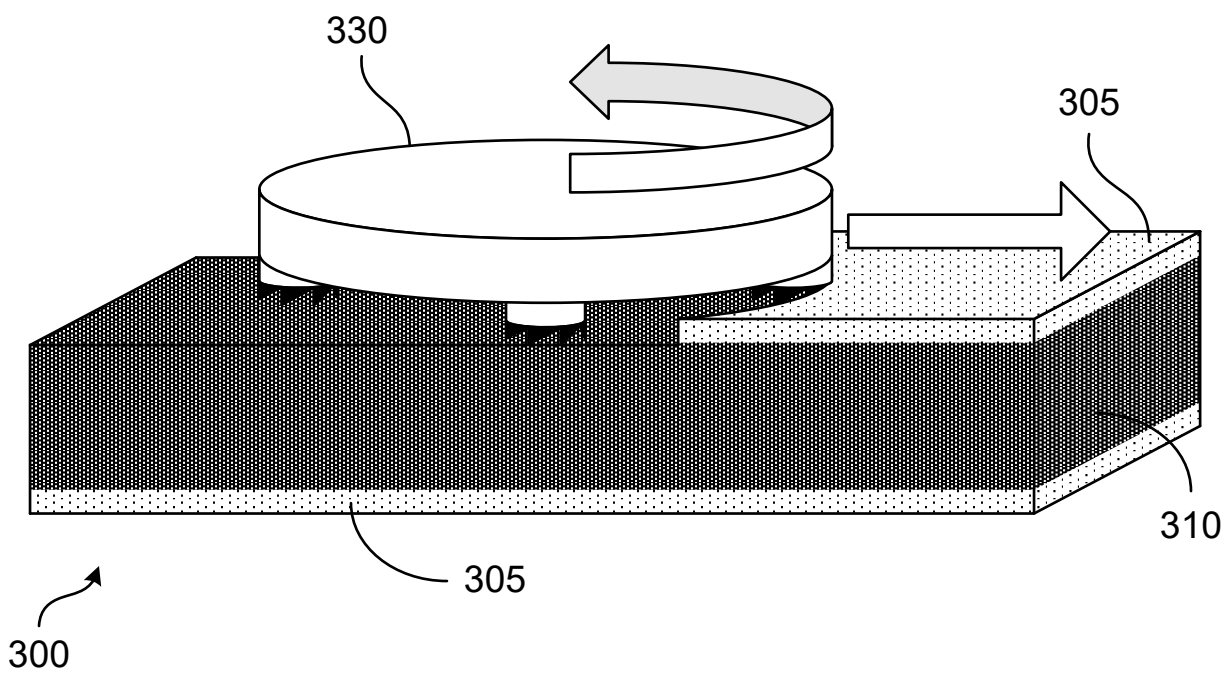


FIG. 3B

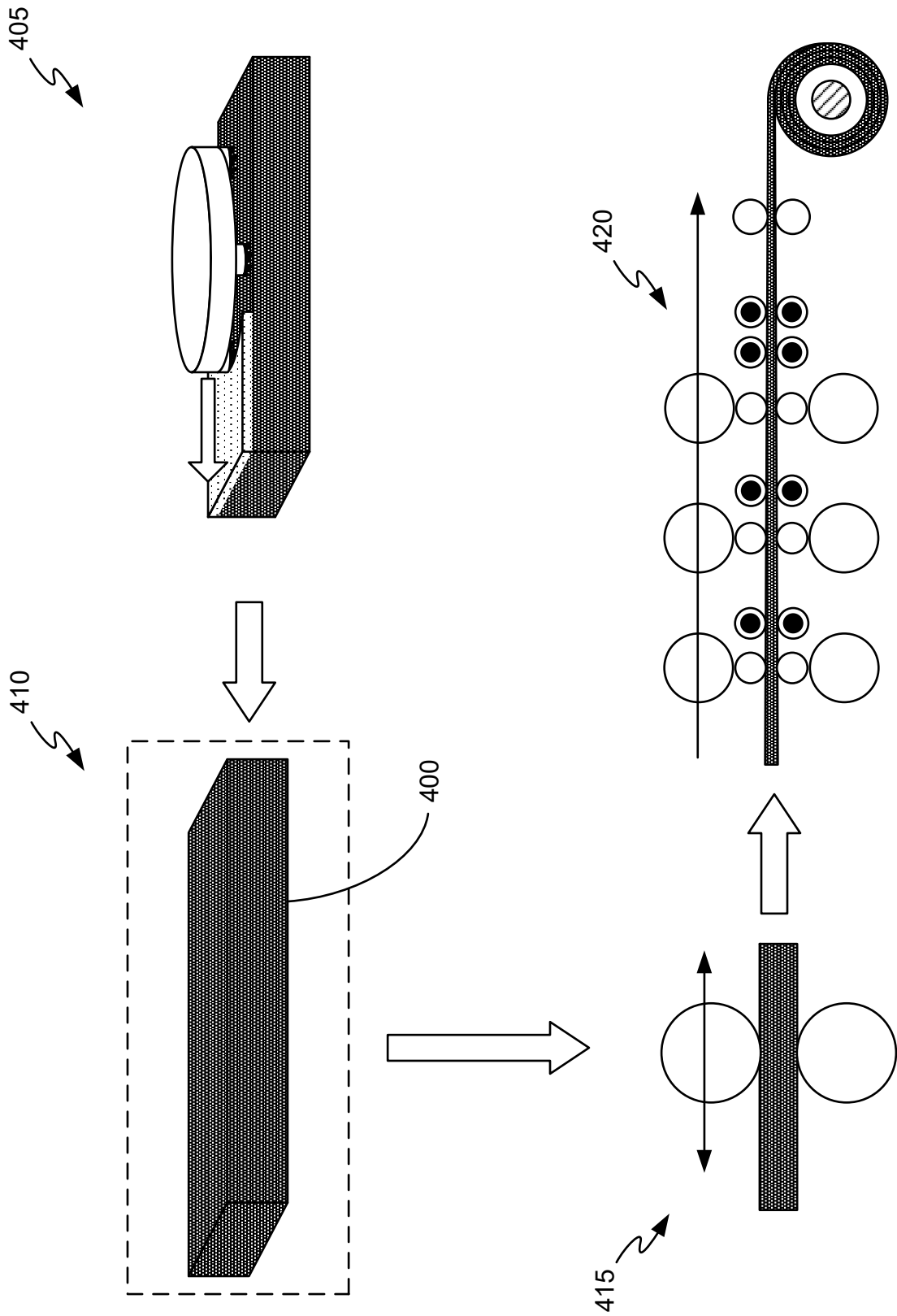


FIG. 4