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(54) **APPARATUS AND METHOD FOR MANUFACTURING A TURBOCHARGER COMPONENT**

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(57) **ABSTRACT**

A method of manufacturing a turbocharger component for an internal combustion engine is disclosed. The method may include introducing a material into a mold, wherein the material includes at least one added alloying element. The method may further include applying a pressure to the material, and solidifying the material by cooling the material at a cooling rate, wherein the solidifying preserves an amount of the at least one added alloying element in solid solution in the material. The method may also include forming precipitates within the material by aging the material at an aging temperature.

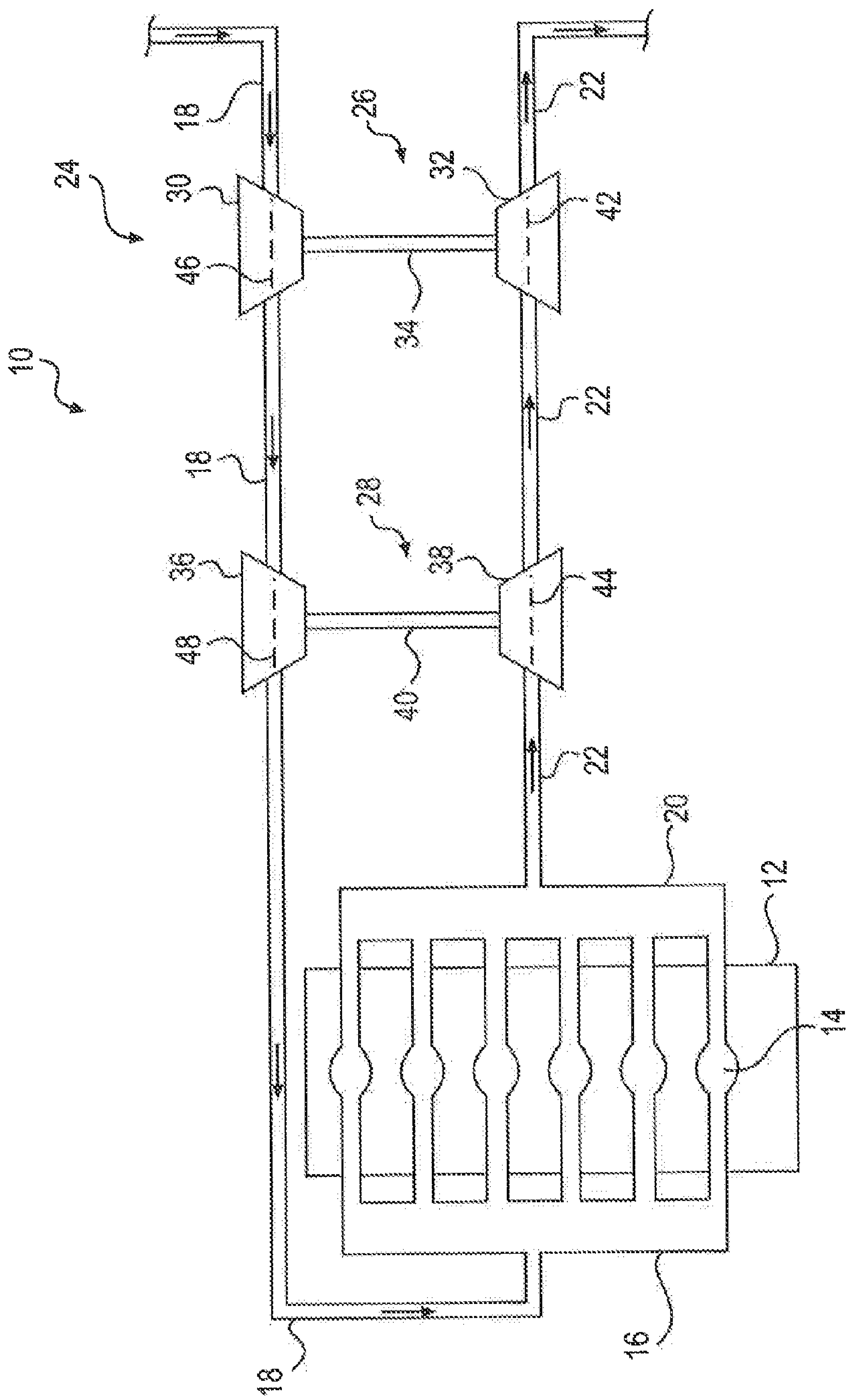

FIG. 1

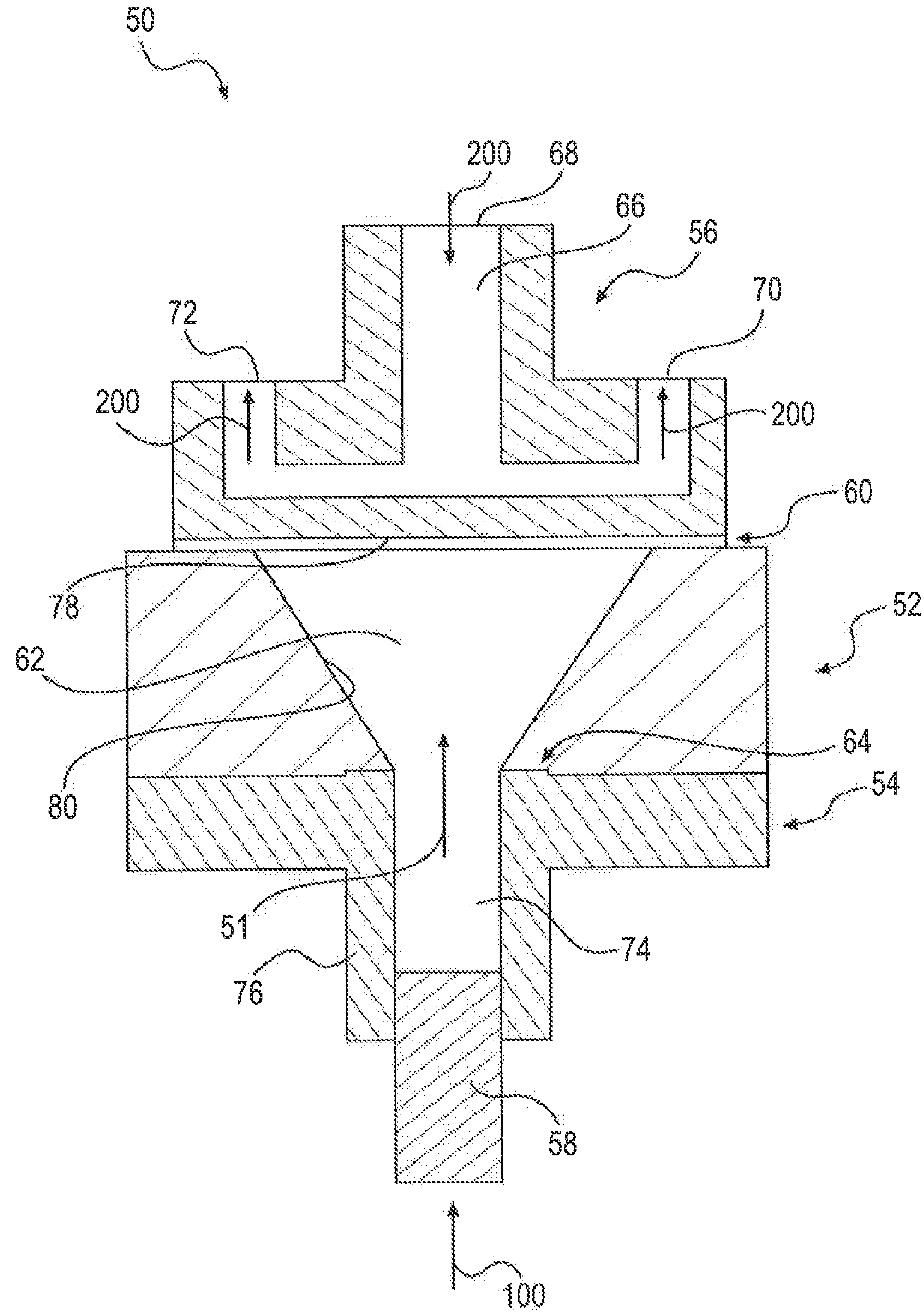

FIG. 2

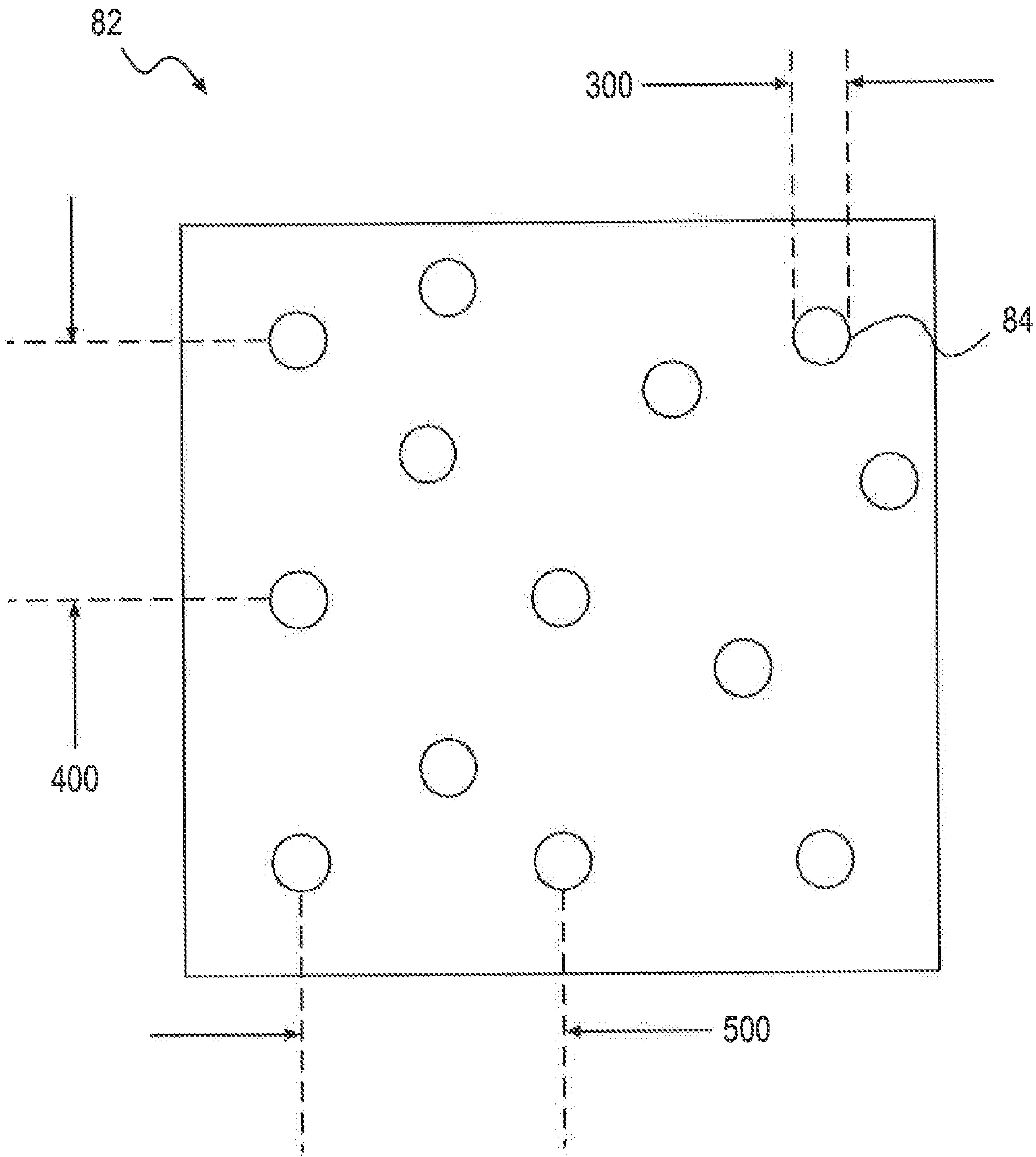

FIG. 3

APPARATUS AND METHOD FOR MANUFACTURING A TURBOCHARGER COMPONENT

TECHNICAL FIELD

[0001] The present disclosure relates generally to a turbocharger system, and more particularly to an apparatus and method for manufacturing a turbocharger component.

BACKGROUND

[0002] Internal combustion engines are supplied with a mixture of air and fuel for subsequent combustion within the engine that generates a mechanical power output. To increase the power generated by the combustion process, the engine may be equipped with a turbocharger system including one or more turbochargers. The turbocharger system can be arranged to use exhaust from the engine to compress air flowing into the engine, thereby forcing more air into a combustion chamber of the engine than could otherwise be draw in to the combustion chamber. The increased supply of air can allow for increased fueling, resulting in an increased power output.

[0003] An internal combustion engine having a turbocharger system may be composed of various components such as one or more turbine wheels, compressor wheels, and/or pistons. Turbocharger components have been constructed from materials capable of withstanding high temperatures and stresses that can be experienced during engine operation. For example, temperatures of compressed air can reach about 260-300° C. during engine operation. Such high operating stresses and temperatures may have an adverse effect on engine operation.

[0004] In an attempt to endure these high temperatures and stresses, turbocharger components, including compressor wheels, have been made of a titanium alloy. Titanium compressor wheels, however, may inhibit efficient engine operation due to their weight, and the costs associated with manufacturing titanium compressor wheels may be excessive. In lieu of using titanium, compressor wheels may be manufactured from aluminum. Aluminum, however, may not be able to withstand the high temperatures and stresses imparted on the compressor wheels during engine operation.

[0005] U.S. Pat. No. 8,118,556 ("the '556 patent") describes a compressor wheel for a turbocharger system. In particular, the '556 patent discloses a compressor wheel formed of an aluminum alloy containing up to 5 weight percent (wt %) scandium. According to the manufacturing process described in the '556 patent, compressor wheels may be manufactured by a number of casting methods, such as vortex casting, vacuum casting, centrifugal casting, die casting, and pressure casting. In one example, molten material is pressure cast into a shell mold and solidifies to form a compressor wheel.

[0006] While an aluminum-scandium alloy like that disclosed in the '556 patent may be used to form a compressor wheel, depending on the manufacturing process, the compressor wheel may still not be able to sufficiently withstand high stresses and operating temperatures in the range of about 260-300° C. The present disclosure is directed to overcoming one or more of the these issues and/or other problems.

SUMMARY

[0007] In one aspect, a method of manufacturing a turbocharger component for an internal combustion engine is disclosed. The method may include introducing a material into a mold, wherein the material includes at least one added alloying element. The method may further include applying a pressure to the material, and solidifying the material by cooling the material at a cooling rate, wherein the solidifying preserves and amount of the at least one added alloying element in solid solution in the material. The method may also include forming precipitates within the material by aging the material at an aging temperature.

[0008] In another aspect, a component for a turbocharger of an internal combustion engine is disclosed. The component may be manufactured by a method including introducing a material into a mold, wherein the material includes at least one added alloying element. The method may further include applying a pressure to the material, and solidifying the material by cooling the material at a cooling rate, wherein the solidifying preserves an amount of the at least one added alloying element in solid solution in the material. The method may also include forming precipitates within the material by aging the material at an aging temperature.

[0009] In yet another aspect, a component for an internal combustion engine is disclosed. The component may include an aluminum-scandium alloy having nanometer-sized precipitates, and the alloy may include about 0.2 wt % scandium.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] FIG. **1** is a schematic view of an internal combustion engine including a turbocharger system according to the present disclosure;

[0011] FIG. **2** is a schematic cross-sectional view of a casting apparatus for making a component of the turbocharger system of FIG. **1**; and

[0012] FIG. **3** is a magnified schematic view of a portion of a compressor wheel of the turbocharger system of FIG. **1**.

DETAILED DESCRIPTION

[0013] FIG. **1** illustrates an exemplary embodiment of an internal combustion engine **10**. Although various internal combustion engines could be provided, for the purposes of illustration, the engine **10** shown in FIG. **1** is a four stroke, compression ignition engine. The engine **10** includes an engine block **12** defining a plurality of combustion chambers or cylinders **14**. Although in the exemplary engine **10**, six combustion chambers **14** are shown, the engine **10** may include any number of combustion chambers **14**. The engine **10** also includes an intake manifold **16** in communication, for example, fluid communication, with the combustion chambers **14**, such that the intake manifold **16** may be capable of providing air to the engine **10** via an intake conduit **18**. An exhaust manifold **20** may also be in communication, for example, fluid communication, with the combustion chambers **14**, such that the exhaust manifold **20** may be capable of expending exhaust gas from the engine block **12** via an exhaust gas conduit **22**.

[0014] The engine **10** may also include a turbocharger system **24**. The turbocharger system **24** may be a single stage turbocharger system or a multiple stage turbocharger system, as shown in FIG. **1**. In one instance, the turbocharger system **24** may include a first turbocharger **26** and a second turbocharger **28**. Although two turbochargers **26**, **28** are shown in

FIG. **1**, in some instances an engine **10** may include one turbocharger or more than two turbochargers. The first turbocharger **26** may include a compressor **30** connected to a turbine **32** via a shaft **34**. Similarly, the second turbocharger **28** may include a compressor **36** connected to a turbine **38** via a shaft **40**.

[0015] During operation of the internal combustion engine **10**, exhaust gas leaving the exhaust manifold **20** passes through the exhaust conduit **22** to turbine wheels **42**, **44**, causing the turbine wheels **42**, **44** to rotate. The rotation of the turbine wheels **42**, **44** turns the shafts **34**, **40**, which rotate compressor wheels **46**, **48**, respectively. Ambient air flows through the intake conduit **18**, and the rotation of the compressor wheels **46**, **48** compresses the ambient air. In some instances, a multiple stage turbocharger system may include compressor wheels operating in series, as shown in FIG. **1**. In other instances, a multiple stage turbocharger system may include compressor wheels positioned and operating in parallel on a common shaft.

[0016] FIG. **2** is a schematic cross-sectional view of a casting apparatus **50**, which may be referred to as a pressure casting apparatus **50**, for making a component of a turbocharger. As described in detail in this disclosure, the casting apparatus **50** may be arranged to cast turbocharger components such as one or more of the turbine wheels **42**, **44**, the compressor wheels **46**, **48**, piston heads (not shown), cylinder heads (not shown), or a variety of other engine components.

[0017] As shown in FIG. **2**, the casting apparatus **50** may include a mold **52**. The mold **52** may include a cavity **62** defined by an interior mold wall **80** and configured to receive a casting material, also referred to as melt stock, during a casting process, as described in detail in this disclosure. In some instances, the mold may be referred to as a "retractable mold" made of multiple separable pieces. In other embodiments, the mold **52** may be constructed as a single piece. Whether the mold **52** is retractable or a single piece, the mold **52** may be either reusable or disposable. As described herein, the mold **52** shown in FIG. **2** is a schematic cross-sectional view of the mold **52**, and therefore may not represent the actual shape of the mold **52** and/or mold cavity **62**. For example, the mold cavity **62** may have a more complex shape into which the casting material can flow based on, e.g., the shape of compressor wheel blades.

[0018] The casting apparatus **50** may further include a ram **54**, which, in some instances, may be a hydraulic ram. As shown in FIG. **2**, the mold **52** may rest or be secured atop the ram **54**. The ram **54** may include a piston **58**, plunger, or similar device configured to introduce the casting material into the mold cavity **62**, as described in this disclosure. The piston **58** may be linearly movable within an interior **74** of a cylinder **76** of the ram **54**. The piston **58** may be movable up to or beyond an upper end **64** of the ram **54**. The volume of casting material that can be contained within the cylinder **76** can be the same or substantially the same as the volume of the mold cavity **62**. In other instances, the volume of casting material that can be contained within the cylinder **76** may be less than the volume of the mold cavity **62**.

[0019] In some instances, the mold **52** and/or the ram **54** may be made from a metal, such as stainless steel. In other instances, the mold **52** and/or the ram **54** may be constructed of another metal. In yet other examples, the mold **52** and/or ram **54** may be made from a non-metallic material, such as sand, which may insulate the molten alloy until solidification via the cooling mold **56** occurs. If the mold **52** and/or the ram **54** are constructed of a non-metallic material, they may be encased by a supporting mechanism such as a metal housing or fixture. The mold **52** and the ram **54** may be either made of the same or different materials.

[0020] The casting apparatus **50** may also include a cooling mold **56** that may rest or be secured atop the mold **52**. The cooling mold **56** may also be referred to as a chill mold, a cooling block, a cooling member, or the like. The cooling mold **56** may include a coolant passage **66** for receiving a coolant and allowing the coolant to flow within the cooling mold **56**. In some instances, the coolant passage **66** may extend from a cooling mold inlet **68** to a pair of cooling mold outlets **70**, **72**. As shown in FIG. **2**, the portion of the coolant passage **66** extending directly from the inlet **68** may be larger than the portion of the coolant passage **66** extending directly from either outlet **70**, **72**. In other embodiments, however, dimensions of the coolant passage **66** (e.g., internal width or diameter) may vary, or the coolant passage **66** may have a constant width or diameter throughout the cooling mold **56**. Additionally, although FIG. **2** shows a single inlet **68** and two outlets **70**, **72**, any number of inlets or outlets may be constructed in the cooling mold **56**. The inlet **68** can be configured to allow a fluid such as coolant to flow into the cooling mold **56**, and each outlet **70**, **72** can be configured to allow the fluid to flow out of the cooling mold **56**. In some instances, the cooling mold **56** may be made of a metal or may be an alloy, such as a copper alloy or steel.

[0021] In some embodiments of the casting apparatus **50**, a gasket **60** or similar device may be disposed between the cooling mold **56** and the mold **52**. The gasket **60** may be also be referred to as an insulation gasket **60**, and may be configured to seal and insulate the casting material within the mold cavity **62** during casting. Due to its position, the gasket **60** may insulate the cooling mold **56** from the mold **52**, which, as described in more detail below, may be preheated prior to casting. The gasket **60** may be annular such that the underside **78** of the cooling mold **56** is exposed to the mold cavity **62**. Thus, an annular gasket **60** may be disposed between the cooling mold **56** and the mold **52**, but not between the cooling mold **56** and the mold cavity **62**, such that casting material in the mold cavity **62** may be in contact with the underside **78** of the cooling mold **56**. In some instances, the contact between the casting material within the mold cavity **62** and the cooling mold **56** may be direct physical contact and/or thermal contact, as described in more detail below.

[0022] FIG. **3** illustrates a magnified schematic view of a portion **82** of one of the compressor wheels **46**, **48** of FIG. **1**. The portion **82** may be a surface portion of one of the compressor wheels **46**, **48** or a portion in a depth direction showing various depths of the material forming one of the compressor wheels **46**, **48**. The portion **82** includes a number of precipitates **84** formed by precipitation occurring after a cooling and solidification process, described in more detail below.

[0023] The process of precipitation may also be referred to as precipitation hardening. Precipitates **84** may be formed in the alloy casting material during an aging process. The precipitates **84** may be located within the cast component (e.g. the compressor wheel) and harden the component by preventing and/or obstructing the movement of irregularities (e.g. dislocations) within the crystal structure of the alloy.

[0024] The precipitates **84** may be referred to as nanometer-sized precipitates having a distance **300** representing a width or diameter of an individual precipitate **84**. In some instances, the distance **300** may be between about 1 and 50 nm. The distance **300** may be substantially the same or vary slightly for each precipitate **84** of the compressor wheel. In some examples, the distance **300** may differ among the multiple precipitates **84** of the compressor wheel due to variations in shape among the precipitates **84**. Although the precipitates **84** are shown in FIG. **3** as being circular, the precipitates **84** may actually have various, irregular shapes.

[0025] FIG. **3** also shows distances **400** and **500** between precipitates **84**. Distance **400** may represent the distance between any one pair of precipitates, while distance **500** may represent the distance between any different pair of precipitates. The distances **400** and **500** may represent the distances between any precipitates in the portion **82**, or in the any of the material forming one of the compressor wheels **46**, **48**. In some instances, the distances **400** and **500** between two pairs of precipitates may be substantially the same, having a value of between about 2 and 40 nm. In one exemplary embodiment, the distances **400**, **500** may be about 25 nm. In other instances, the distances **400** and **500** may differ. When the distances **400**, **500** are substantially the same throughout one of the compressor wheels **46**, **48**, the precipitates **84** may be referred to as being uniformly distributed throughout the compressor wheels **46**, **48**. When the distances, such as the distances **400**, **500**, between precipitates **84** vary throughout one of the compressor wheels **46**, **48**, the precipitates **84** may be referred to as being non-uniformly or randomly distributed throughout the compressor wheels **46**, **48**.

[0026] FIG. **3** shows only a portion **82** of one of the compressor wheels **46**, **48**, and additional precipitates **84** may be arranged in a similar fashion in other portions or throughout the material forming the entire structure of the compressor wheels **46**, **48**. Furthermore, the values for the distances **300**, **400**, **500** are exemplary only. Distances **300**, **400**, **500** may be greater than or less than the values described herein.

[0027] An exemplary method of manufacturing a compressor wheel using the casting apparatus **50** shown in FIG. **2** will now be described. The chemistry of the casting material, which may also be referred to as melt stock, an alloy, a molten alloy, an alloy material, an alloy casting material, or the like, may include one or more of the following: copper, magnesium, zinc, nickel, iron, scandium, zirconium, titanium, aluminum, manganese, chrome, lithium, and silicon. For example, the alloy may include about 1 to 4 wt % copper, 0 to 3 wt % magnesium, 0 to 7 wt % zinc, 0 to 2 wt % nickel, 0 to 2 wt % iron, at least one of the following: up to about 2 wt % scandium, 0 to 2 wt % zirconium, and 0 to 1 wt % titanium, with the balance of the alloy being aluminum. Other alloy materials may also be used. In some instances, various elements such as strontium and sodium may also be used in the casting material and may be referred to as modifying elements or microstructure modifiers. The scandium, zirconium, and titanium may each be referred to herein as an added alloying element, added alloying material, added material, or the like. In one instance, the alloy may be an aluminum-scandium alloy including up to about 5 wt % scandium. In another instance, an aluminum-scandium alloy may include up to about 2 wt % scandium. As used herein, "wt %" indicates a given element's percentage of the total weight of the alloy. The alloy may be melted and held at a temperature for a period of time. In one instance, the alloy may be held at about 750° C. for about thirty minutes, at which point the temperature may be lowered to about 730° C. before the alloy is ready to be introduced into the mold **52**.

[0028] At a time either before or after the alloy is being melted, or during the melting of the alloy, one or more of the mold **52**, the ram **54**, and the cooling mold **56** can be prepared for casting. The mold **52** and/or the ram **54** may be preheated by one or more heating elements (not shown). Various types of heating elements may be used. For example, the heating element may be one or more internal passages formed within the mold **52** and/or the ram **54** through which a heated fluid (e.g. oil) may flow. The internal passages may have a variety of cross-sections (e.g. circular cross-sections) and may be arranged in any fashion within the mold **52** and/or ram **54**. For instance, the internal passages may be a plurality of linear passages extending through the mold **52** and/or ram **54**, or the internal passages may one or more curved or helical passages within the mold **52** and/or ram **54**. In other examples, the heating element may be an induction coil or electrical resistive heating element disposed on the outside of the mold **52** and/or the ram **54**. In one instance, the heating element may preheat the mold **52** and/or ram **54** to a temperature of about 200° C. prior to casting.

[0029] To prepare the cooling mold **56** for casting, a coolant can be introduced into the coolant passage **66** via the inlet **68** to flow in a direction **200** towards the outlets **70**, **72**. In some instances, the inlet **68** may serve as an outlet and the outlets **70**, **72** may serve as inlets such that the coolant flow direction **200** can be reversed.

[0030] After the molds **52** and **56** are prepared, pressure casting may begin. Pressure casting may also be referred to as pressurized casting, and may encompass processes such as squeeze casting. To begin casting the compressor wheel, the piston **58** may advance within the cylinder **76** toward the mold cavity **62** in a direction **100** to pressurize the casting material, which, as described herein, may be an aluminum-scandium alloy. In some instances, the piston **58** may move in the direction **100** until the piston **58** reaches the upper end **64** of the ram **74**. As the piston **58** moves in the direction **100**, the alloy can be pressurized and introduced into the mold **52**, specifically, into the mold cavity **62**. The general flow of the alloy (i.e. the casting material) into the mold cavity **62** may be represented by arrow **51** in FIG. **2**. As the piston **58** moves in the direction **100**, the alloy fills the mold cavity **62**, first from the a bottom portion of the mold (near the upper end **64** of the ram **54**) then to the top of the mold (near the underside **78** of the cooling mold **56**), as shown in FIG. **2**. During casting, the pressure may be greater than about 1 MPa (about 0.145 ksi). In some instances, the pressure may be between about 10 and 100 MPa (about 1.45 and 14.5 ksi). The pressure may vary depending on, e.g., the geometry of the component being cast, which can determine the shape of the mold cavity **62**.

[0031] After the mold cavity **62** is filled with the alloy, the pressure may no longer be applied. In some instances, the pressure may continue to be applied after the mold cavity **62** is filled with the alloy for a period of time until solidification of the alloy completes, which is described in more detail below, and/or until a temperature of the compressor wheel, also referred to as the casting temperature, reaches about 300° C. In some instances, the period of time after casting during which the pressure may continue to be applied can be between about 1 and 10 seconds, or between about 3 and 5 seconds.

[0032] After the mold cavity is substantially or entirely filled with the aluminum-scandium alloy casting material, solidification may take place to form a solid component, such as a compressor wheel, also referred to as a casting. Solidification may occur when the mold cavity **62** is filled such that the aluminum-scandium alloy contacts (e.g. directly, physically contacts) the underside **78** of the cooling mold **56**. In one example, solidification may begin when the casting material first physically contacts the underside **78** of the cooling mold **56**. In other instances, solidification may begin when the casting material is introduced into the mold cavity **62**; however, most of the solidification may not take place until the casting material physically contacts the underside **78** of the cooling mold **56** having coolant flowing therethrough. Unless specified, "contact" may refer to direct or physical contact, or thermal contact. Once the mold cavity **62** is filled and the alloy contacts the underside **78** of the cooling mold **56**, heat may be transferred directly from the alloy to the mold, causing the alloy to cool and solidify to form a solid solution aluminum-scandium alloy. Thus, the cooling mold **56** can draw out the heat from the casting material disposed within the mold cavity **62**. The solid solution aluminum-scandium alloy may also be referred to herein as solid solution, a solid solution alloy, a solid solution casting, or the like. In the example of manufacturing a compressor wheel, cooling and solidification may occur with a back-disk of the compressor wheel being the portion of the alloy in physical contact with the underside **78** of the cooling mold **56**. Solidification during the casting method described herein may preserve at least some of the amount of scandium within the molten alloy. In some examples, the disclosed solidification process may preserve all or substantially all of the scandium in solid solution within the casting material. For instance, where scandium makes up about 0.2 wt % of the casting material when the material is first introduced into the mold **52**, scandium may still make up about 0.2 wt % of the casting material after solidification with about 0.2 wt % of the scandium in solid solution in the solidified casting.

[0033] When solidification is complete, the mold **52** may be opened and the compressor wheel can be removed from the mold cavity **62**. If the mold **52** is a retractable mold composed of multiple pieces, one or more pieces of the mold **52** may be removed to allow for removal of the compressor wheel from the mold **52**. If the mold **52** is a single piece, the mold **52** may be broken open to allow for removal of the compressor wheel.

[0034] After casting, once the compressor wheel is completely cooled, the compressor wheel may be aged at a temperature, which may be referred to as an aging temperature, for a period of time. In some instances, the aging temperature may be between about 200° C. and 400° C. (e.g. about 300° C.), and the aging time may be between about 1 and 24 hours (e.g., between about 2 and 8 hours). Prior to aging the compressor wheel, the compressor wheel may be pre-aged at a temperature for a period of time. The pre-aging temperature may be lower than the aging temperature, and the pre-aging time may be longer than the aging time. For example, the pre-aging temperature and time may be about 150° C. and about 20 hours, respectively.

[0035] During the aging process, the precipitates **84** may be formed within the casting. Specifically, Al_3Sc nanoscale or nanometer-sized precipitates may be formed. In some instances, the precipitates **84** may be non-uniformly or randomly distributed nanometer-sized precipitates **84**, as shown in and discussed with respect to FIG. **3**. In other instances, the precipitates **84** may be uniformly distributed in a portion, such as the portion **82**, or throughout the entire compressor wheel **46**, **48**.

[0036] The precipitates **84** may be formed as a result of preserving the amount of scandium in solid solution during solidification. For example, the final amount of scandium in solid solution after solidification may be between about 50 and 100% (e.g., about 80 or 90%), of the initial amount of scandium in the casting material before solidification. In some instances, excess scandium can be initially provided in the casting material to achieve a desired final amount of scandium in solid solution during and after solidification. For example, to achieve 0.2 wt % scandium in solid solution after solidification, an initial amount of scandium greater than 0.2 wt % can be provided in the casting material. The amount of scandium initially provided in the casting material may be slightly greater than the desired final amount of scandium in solid solution, or the amount of scandium initially in the casting material may be substantially greater than the desired final amount of scandium. For instance, to achieve a greater amount of scandium in solid solution after solidification, e.g., between about 1 and 5 wt % scandium, the amount of scandium initially in the casting material may be substantially greater than between about 1 and 5 wt % scandium. On the other hand, to achieve a lesser amount of scandium in solid solution after solidification, e.g. about 0.2 wt % scandium, the amount of scandium initially in the casting material may be slightly greater than or substantially equal to about 0.2 wt % scandium. An initial amount of scandium may be considered "slightly greater" than the final amount if after solidification there is between about 0% and 30% less scandium in solid solution than in the initial casting material before solidification. An initial amount of scandium may be considered "substantially greater" than the final amount if after solidification there is between about 30% and 95% less scandium in solid solution than in the initial casting material before solidification. Furthermore, the amount of scandium initially in the casting material being slightly greater than or substantially equal to the amount of scandium in solid solution after solidification may be referred to herein as preserving a "substantial amount" of scandium, or another alloying element. In some instances, the amount of scandium preserved can be all or substantially all of the scandium initially in the casting material.

[0037] As described herein, during solidification the alloy may be rapidly cooled, or quenched, within the mold cavity **62** by the cooling mold **56** to preserve at least some of the amount of scandium initially in the casting material. The cooling rate applied to the alloy, which may be a predetermined cooling rate, may be sufficient to keep the scandium in solid solution in the casting material. For example, the cooling rate may be between about 5° and 200° C./second (between about 41° F. and 392° F./second). In one instance, the cooling rate may be about 100° C./second (about 212° F./second). In another instance, the cooling rate may be about 40° C./second (about 104° F./second). The cooling rate may also be referred to herein as the "solidification rate" because the cooling rate may determine the length of time required to solidify the molten alloy within the mold **52** to form the compressor wheel. Rapidly cooling the alloy may cause the alloy to solidify directly from a given temperature (e.g. a liquidus temperature), such that an amount of the scandium remains in solid solution in the casting material. For example, after solidification, scandium may make up about 0.2 wt % or more of the casting material by rapidly cooling the alloy as described herein. Because scandium is preserved in solid solution in the casting material, during the aging process precipitates, specifically Al_3Sc nanometer-sized precipitates, can be formed in the compressor wheel material. For example, aging a compressor wheel cast according to the method described herein at about 300° C. for about 2 hours can use the amount of scandium preserved in solid solution during solidification to produce a plurality of Al_3Sc nanometer-sized precipitates. In some instances, the amount of precipitates formed may be substantially the same as the amount of scandium in the casting material before and/or after solidification (e.g. about 0.2 wt %).

INDUSTRIAL APPLICABILITY

[0038] The above-described method and apparatus, while being described with respect to a compressor wheel of a turbocharger in an internal combustion engine, can be used generally in applications or industries (e.g. the automotive, gas turbine, or aerospace industries) involving components requiring high temperature and/or stress resistance. Additionally, the above-described method and apparatus can be used in applications or industries requiring lightweight components.

[0039] The method and apparatus of the present disclosure can provide a viable alternative to titanium engine components such as compressor wheels. In particular, the present disclosure can enable effective utilization of an alloying element such as scandium in the manufacture of aluminum-scandium alloy compressor wheels. As described herein, during manufacturing the alloy can be rapidly cooled by the cooling mold **56** configured to have a coolant flowing therethrough. This rapid cooling can cause solidification of the alloy to form the compressor wheel casting within the mold **52**. The high cooling rate can preserve an amount of scandium in solid solution in the casting material, so that during the aging process, many nanometer-sized precipitates **84** (e.g. Al_3Sc precipitates) can be formed within the casting. For example, based on the disclosed method, scandium may make up about 0.2 wt % or more of the casting.

[0040] Due to the formation of many precipitates **84** within the casting, the compressor wheel can have high temperature and/or stress properties to enable the aluminum-scandium alloy compressor wheel to withstand high operating temperatures and stresses of an internal combustion engine. The formation of precipitates can prevent dislocation moving, and in doing so may increase the strength (e.g. the tensile strength and/or the yield strength) of the compressor wheel and decrease its malleability. In some instances, the aluminum-scandium alloy compressor wheel may withstand operating temperatures of about 260-300° C., and in some cases greater than about 300° C. Additionally, the formed compressor wheel may have a tensile strength of greater than or equal to about 250 MPa (about 36.25 ksi) to meet the high stress requirements.

[0041] Pressurized casting can facilitate rapid cooling, which may help to entrap alloying elements in solid solution, and thus allow for the formation of precipitates **84** within the compressor wheel during the subsequent aging process. During manufacturing, air gaps may exist between one or more sides of the mold **52** and/or the underside **78** of the cooling mold **56**. The pressurized casting process can reduce the size of, or altogether eliminate, the air gaps. Reduction in size and/or elimination of the air gaps can improve heat transfer between the alloy casting material and the molds **52**, **56**, which can facilitate rapid cooling of the casting material and the eventual formation during the aging process of nanometer-sized precipitates **84** therein. For example, pressure casting may increase the heat transfer coefficient by causing direct physical contact between the compressor wheel being cast and the underside **78** of the cooling mold **56**, thereby improving heat transfer from the compressor wheel to the cooling mold **56**.

[0042] The pressure casting process described herein, which may include preheating the mold **52** and/or ram **54**, may also help to avoid premature solidification of the alloy casting material within the mold **52**. As described herein, the casting material may not contact the underside **78** of the cooling mold **56**, and therefore may not be substantially cooled and solidified, until the mold cavity **62** is completely filled with the casting material. Moreover, the mold **52** and/or ram **54** may be preheated to help prevent early solidification of the casting material. In addition to the pressure casting process itself, the arrangement of the mold **52**, the cooling mold **56**, and the ram **54** may allow for the mold cavity **62** to be filled with casting material from the bottom portion (i.e. near the upper end **64** of the ram **54**) to the top portion (i.e. near the underside **78** of the cooling mold **56**). Thus, the arrangement can prohibit contact between the casting material and the underside **78** of the cooling mold **56** until the mold cavity **62** is filled, thereby helping to prevent premature solidification of the alloy casting material. In some instances, pressure casting may also reduce porosity of the casting material and thus eliminate other porosity reducing processes, such as hot isostatic processing, which may reduce the formation of nanometer sized precipitates (e.g. Al_3Sc) and lose some or all strengthening benefits from alloying elements. Additionally, forming the mold **56** of a thermally conductive alloy, such as copper or stainless steel, may further facilitate heat transfer from the casting material to the mold **56**.

[0043] Using an aluminum-scandium alloy to form a turbocharger component such as a compressor wheel may also allow for cost savings when compared to another alloy, such as titanium. Additionally, an aluminum-scandium alloy compressor wheel formed by the process described herein may be lightweight, so as to reduce inertia of a turbocharger rotor, and thus increase the turbocharger response and performance. Compared to titanium, aluminum alloys may be about 40% lighter than typical titanium alloys. Therefore, providing an aluminum-scandium compressor wheel may increase engine transient response and reduce turbo-lag, while also improving fuel efficiency during engine operation.

[0044] When the manufacturing method described herein is used to cast a compressor wheel or other component potentially having a complex geometry, the mold **52** may be formed as a retractable, multiple-piece mold having a plurality of separable parts. These separable parts may be referred to as segments, modules, or the like. Providing a retractable mold **52** may allow for the component to be easily removed from the mold **52** after casting.

[0045] The compressor wheel of the present disclosure may be used in various turbocharger systems. Although FIG. **1** shows a multiple stage turbocharger system, the compressor wheel of the present disclosure may be used in a single stage turbocharger system. Furthermore, the compressor wheel of the present disclosure may be used in a first stage of a compressor and/or in one or more later stage compressors. Moreover, although the disclosed method and apparatus may refer to compressor wheels, the method and apparatus may be applicable to components other than compressor wheels. For example, the disclosed method and apparatus may be applicable to other turbocharger or internal combustion engine components such as turbine wheels, cylinder heads, piston heads, or the like. In addition, the method and apparatus may be applied to a variety of other internal combustion engine components, or to components used in various other industries and applications. Also, although the disclosed method and apparatus may refer to using scandium as an added material to form an aluminum-scandium alloy, the method and apparatus may be applicable to added materials other than scandium, such as zirconium and titanium. Furthermore, with regard to the mold **52**, although the material forming the mold **52** may be stainless steel, other alloys (e.g. copper alloy) may be used depending on the geometry of the component being cast.

[0046] It will be apparent to those skilled in the art that various modifications and variations can be made to the disclosed apparatus and method for manufacturing a turbocharger component. Other embodiments will be apparent to those skilled in the art from consideration of the specification and practice of the disclosed apparatus and method. It is intended that the specification and examples be considered as exemplary only, with a true scope being indicated by the following claims and their equivalents.

What is claimed is:

1. A method of manufacturing a turbocharger component for an internal combustion engine, the method comprising:

introducing a material into a mold, wherein the material includes at least one added alloying element;

applying a pressure to the material;

solidifying the material by cooling the material at a cooling rate, wherein the solidifying preserves an amount of the at least one added alloying element in solid solution in the material; and

forming precipitates within the material by aging the material at an aging temperature.

2. The method of claim **1**, wherein the cooling rate is between about 5° C. per second and 200° C. per second.

3. The method of claim **1**, wherein the material is an aluminum-scandium alloy.

4. The method of claim **3**, wherein the aluminum-scandium alloy includes about 0.2 wt % scandium as the at least one added alloying element.

5. The method of claim **1**, wherein the pressure is applied to the material during and after the material is introduced into the mold and until the material solidifies.

6. The method of claim **1**, wherein the precipitates are nanometer-sized precipitates of the at least one added alloying element randomly distributed throughout the turbocharger component.

7. The method of claim **1**, wherein the mold includes a mold cavity, and wherein the solidifying occurs when the material fills the mold cavity.

8. The method of claim **1**, wherein during the solidifying the material contacts a cooling mold.

9. The method of claim **8**, wherein the solidifying preserves a substantial amount of the at least one added alloying element in solid solution in the material.

10. The method of claim **8**, wherein the mold includes a mold cavity, and wherein the material first contacts the cooling mold when the material fills the mold cavity.

11. The method of claim **1**, wherein the material is first introduced into a bottom portion of the mold.

12. The method of claim **1**, wherein a coolant is introduced into a coolant passage of a cooling mold disposed above the mold.

13. The method of claim **1**, wherein the turbocharger component is a compressor wheel.

14. A component for a turbocharger of an internal combustion engine, wherein the component is manufactured by the method comprising:

introducing a material into a mold, wherein the material includes at least one added alloying element;

applying a pressure to the material;

solidifying the material by cooling the material at a cooling rate, wherein the solidifying preserves an amount of the at least one added alloying element in solid solution in the material; and

forming precipitates within the material by aging the material at an aging temperature.

15. The component of claim **14**, wherein the cooling rate is between about 5° C. per second and 200° C. per second.

16. The component of claim **14**, wherein the material is an aluminum-scandium alloy including about 0.2 wt % scandium as the at least one added alloying element.

17. The component of claim **14**, wherein the precipitates are uniformly distributed nanometer-sized precipitates.

18. The component of claim **14**, wherein the aging temperature is between about 200° C. and 400° C.

19. A component for an internal combustion engine, wherein the component comprises:

an aluminum-scandium alloy having nanometer-sized precipitates, wherein the alloy includes about 0.2 wt % scandium.

20. The component of claim **19**, wherein the precipitates are randomly distributed throughout the component.

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