

IMPROVED FORMULATION OF WATER-SOLUBLE CERAMIC CORES FOR
INVESTMENT CASTING TO ENHANCE HIGH TEMPERATURE
STRUCTURAL INTEGRITY

5 **Cross-Reference to Related Application**

[0001] This application claims the benefit of priority of Singapore Patent Application No. 10202302230V, filed 4 August 2023, the content of it being hereby incorporated by reference in its entirety for all purposes.

10 **Technical Field**

[0002] The present disclosure relates to a ceramic core and a method of forming the ceramic core. The present disclosure relates to an investment casting method.

Background

15 [0003] Investment casting may be traditionally one of the most cost-effective and efficient ways to produce aerospace and automobile parts. In investment casting, traditionally, ceramic cores may be used, for example, in forming aerospace and automobile parts having designs that involve complicated, intricate, or very small, internal cavities or channels or structures. Removal of the ceramic cores from a formed
20 part may require harsh conditions and/or corrosive chemicals. Also, the chemical leaching process for removal of the ceramic core may be energy consuming, may have an adverse impact on environment, and hence fabrication of the ceramic core may be costly.

[0004] To minimise negative impact on the environment, water-soluble ceramic cores
25 may have been developed. Water-soluble ceramic cores may often be used in investment casting, for example, forming aerospace and automobile parts having designs that involve complicated, intricate, or very small, internal cavities or channels or structures, as the water-soluble ceramic cores may be easily removed by water after the investment casting and with minimal impact to the environment. However, the
30 water-soluble ceramic cores may have to be pre-heated to more than 1000°C (e.g., 1050°C) during the investment casting process prior to having a molten metal poured into a mold, which tend to cause structural disintegration of the water-soluble ceramic

cores through delamination. In addition, the heat shock from the molten metal (about 1600°C for molten steel) may cause the water-soluble ceramic cores to disintegrate structurally. FIG. 1 shows delamination of a water-soluble ceramic core after being heated directly to about 1000°C.

- 5 [0005] There is thus a need to provide for a solution that addresses one or more of the limitations mentioned above. The solution should at least provide for an improved ceramic core.

Summary

[0006] In a first aspect, there is provided a water-soluble ceramic core comprising:

- 10 a metal oxide comprising an alkaline earth metal;
 a carbon material comprising graphite;
 a reinforcement agent; and
 a binder.

[0007] In another aspect, there is provided a method for forming the water-soluble ceramic core described in the first aspect of the present disclosure, the method comprising:

- 15 providing a slurry mixture comprising the metal oxide, the carbon material, the reinforcement agent, and water, wherein the carbon material comprises graphite;
 mixing the slurry mixture and the binder;
20 forming a core from the slurry mixture; and
 curing the core to form the water-soluble ceramic core.

[0008] In another aspect, there is provided an investment casting method comprising:
 providing the water-soluble ceramic core described in the first aspect of present disclosure;

- 25 heating the water-soluble ceramic core to a first temperature; and
 heating the water-soluble ceramic core from the first temperature to a second temperature, wherein the first temperature is lower than the second temperature.

Brief Description of the Drawings

- 30 [0009] The drawings are not necessarily to scale, emphasis instead generally being placed upon illustrating the principles of the present disclosure. In the following

description, various embodiments of the present disclosure are described with reference to the following drawings, in which:

[0010] FIG. 1 shows delamination of a traditional water-soluble ceramic core after heating directly to about 1000°C. In other words, the traditional water-soluble ceramic core in this instance is heated continuously until about 1000°C without pausing at any intermediate temperature.

[0011] FIG. 2 shows a sample of a ceramic core of the present disclosure. The ceramic core was subjected to pressing, and curing at 200°C.

[0012] FIG. 3 shows a heat treatment regime described in aspects of the present disclosure for pre-heating before investment casting of stainless steel (involving a ceramic core of the present disclosure). Said differently, FIG. 3 shows a heat treatment regime applied to the ceramic core before commencing investment casting. The heat treatment regime may be included as one of the steps in an investment casting method, for example, the heat treatment regime may be carried out followed by investment casting.

[0013] FIG. 4 shows a ceramic core of the present disclosure that was subjected to the heat treatment regime in FIG. 3. The first stage of heating (“pre-heating”) is carried out at 500°C, which is developed to dissipate any residual stress in the ceramic core. Specifically, FIG. 4 shows that the ceramic core, after such a heat treatment regime, does not suffer any cracks and delamination.

[0014] FIG. 5 is a table identifying the flexural strength of various ceramic samples with different amounts of binder (e.g., MgSO₄) and reinforcement agent (e.g., kaolinite).

[0015] FIG. 6 is a table comparing performances (e.g., flexural strength and shrinkage) of a traditional ceramic core and a ceramic core of the present disclosure before and after the heat treatment regime (e.g., see FIG. 3, heating to 1050°C). The sonication in water and external pressure were applied after the heat treatment.

[0016] FIG. 7 is a photograph comparing a part (left) formed using a traditional ceramic core (and after traditional investment casting) and a part (right) formed using a ceramic core (and after investment casting that includes the heat treatment regime) of the present disclosure, both parts are of stainless steel. The ceramic core (in both parts) is already removed. It can be seen that the rectangular channel formed in the part using the ceramic

core and the investment casting method of the present disclosure is better defined (the part shown in the right).

[0017] FIG. 8 is a photograph comparing a part (left) formed using a traditional ceramic core (and after traditional investment casting) and a part (right) formed using a ceramic core (and after investment casting that includes the heat treatment regime) of the present disclosure, both parts are of an aluminum alloy. The ceramic core (in both parts) is already removed. It can be seen that the rectangular channel formed in the part using the ceramic core and the investment casting method of the present disclosure is better defined (the part shown in the right).

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Detailed Description

[0018] The following detailed description refers to the accompanying drawings that show, by way of illustration, specific details and embodiments in which the present disclosure may be practiced.

15 [0019] Features that are described in the context of an embodiment may correspondingly be applicable to the same or similar features in the other embodiments. Features that are described in the context of an embodiment may correspondingly be applicable to the other embodiments, even if not explicitly described in these other embodiments. Furthermore, additions and/or combinations and/or alternatives as
20 described for a feature in the context of an embodiment may correspondingly be applicable to the same or similar feature in the other embodiments.

[0020] The present disclosure relates to a ceramic core. The present disclosure describes compositions of the ceramic core, and a method for forming the ceramic core. The ceramic core may be a water-soluble ceramic core. The water-soluble ceramic core
25 may be referred to in the present disclosure as a “ceramic core” for brevity.

[0021] Traditionally, a ceramic core may be used in investment casting. Investment casting may be a method used for forming an aerospace part, an automobile part, etc. Such part may have intricate or complicated designs, such as involving considerably small, internal cavities or channels or structures. Traditionally, in investment casting,
30 the ceramic core may be placed in a mold, which a molten metal may be later poured into, to help in forming such intricate or complicated designs. However, the ceramic core tends to suffer from thermal stress during investment casting, resulting in cracks

or delamination. Also, traditionally, removal of the ceramic core from the formed part may require environmentally harmful and/or harsh chemicals, or even an energy intensive process.

5 [0022] The ceramic core of the present disclosure circumvents one or more of the issues mentioned above. Advantageously, the ceramic core of the present disclosure has improved thermal resistance. That is to say, the ceramic core of the present disclosure is able to withstand higher temperatures or thermal shock without being susceptible to having its structural integrity compromised (e.g., cracking or delamination) compared to traditional ceramic cores. Said differently, the ceramic core of the present disclosure
10 advantageously has its high temperature structural integrity enhanced. At the same time, the ceramic core of the present disclosure remains water-soluble, i.e., able to collapse in water (i.e., water collapsibility) for easier removal, even with the improved thermal resistance. Further advantageously, the ceramic core of the present disclosure has better flexural strength over traditional ceramic cores.

15 [0023] The present disclosure, as mentioned above, relates to a method for forming the ceramic core. The present method involves an improved formulation for forming the ceramic core, which helps enhance the high temperature structural integrity and flexural strength of the ceramic core as compared to traditional ceramic cores. At the same time, water collapsibility of the ceramic core is still retained for ease of removal.

20 [0024] The present disclosure relates to an investment casting method that also helps in reducing (or even eliminating) cracks and delamination. In other words, the investment casting method of the present disclosure is advantageous in helping confer better thermal resistance and flexural strength to the ceramic core of the present disclosure (with the ability to be removed by water retained), i.e., the ceramic core may
25 still be easily removed after investment casting and yet continue to have sufficient structural integrity to survive the high temperatures used in investment casting. The investment casting method of the present disclosure may involve a heat treatment regime that includes a “pre-heating” step, which helps minimize delamination in ceramic cores, including traditional ceramic cores.

30 [0025] Advantageously, the ceramic core (and the method for forming the ceramic core and the investment casting method) of the present disclosure, provide an improved formulation of a ceramic core (e.g., a water-soluble ceramic core) having greater

flexural strength both before and after the heat treatment regime compared to traditional ceramic cores and ceramic cores formed from traditional methods. In addition to the enhanced structural integrity under high temperatures (even at 1050°C), the ceramic core of the present disclosure suffers less dimensional shrinkage, and readily collapses
5 in water upon sonication and external pressure for ease of removal.

[0026] Details of various embodiments of ceramic core of the present disclosure, method for forming the ceramic core, and an investment casting method of the present disclosure, and advantages associated with the various embodiments are described below. Where the embodiments and advantages are described in the examples section
10 further hereinbelow, they shall not be iterated for brevity.

[0027] The present disclosure describes, in a first aspect, a ceramic core. The ceramic core may be water-soluble. The ceramic core, e.g., the water-soluble ceramic core, may include a metal oxide including an alkaline earth metal, a carbon material, a reinforcement agent, and a binder. In various embodiments, the carbon material may
15 include graphite.

[0028] In various aspects and embodiments, the metal oxide may include magnesium oxide, calcium oxide, and/or barium oxide. Advantageously, such metal oxides may be non-toxic (or less harmful) to environment and more economical. Such metal oxides are more thermally stable due to their considerably high melting point, and together
20 with the other components or even in the presence of other components, confer better thermal stability to the water-soluble ceramic core.

[0029] In various aspects and embodiments, the carbon may consist of graphite. Graphite is advantageous, as it is an excellent refractory material due to its high temperature resistance, high thermal conductivity and low thermal expansivity. As
25 such, graphite, together with the other components or even in the presence of other components, confer better thermal stability to the water-soluble ceramic core. Also, graphite may be more economical than carbon nanotubes.

[0030] In various aspects and embodiments, the reinforcement agent may include kaolinite, boron carbide (B_4C), silicon carbide (SiC), aluminum oxide (Al_2O_3), and/or
30 silicon dioxide (SiO_2). Such reinforcement agents, together with the other components or even in the presence of other components, improve the mechanical properties (e.g., flexural strength) of the water-soluble ceramic core.

[0031] In various aspects and embodiments, the binder may include magnesium sulfate, potassium carbonate, starch, and/or polyacrylic acid. Such binders are water-soluble, and together with the other components or even in the presence of other components, confer water collapsibility to the water-soluble ceramic core. As one non-limiting
5 example, magnesium sulfate at high temperatures may decompose to magnesium oxide, which forms a component of the water-soluble ceramic core, and this may prevent any cross contamination.

[0032] In various aspects and embodiments, the metal oxide, the carbon material, the reinforcement agent, and the binder, may be mixed in a weight ratio of 24:24:1:1.

10 [0033] In various aspects and embodiments, the ceramic core of the present disclosure may be in any shape, e.g., rectangular, spherical, hemispherical, cube, tubular, triangular.

[0034] The present disclosure describes a method for forming the ceramic core described in various aspects and embodiments of the present disclosure. Embodiments
15 and advantages described for the ceramic core of various aspects of the present disclosure can be analogously valid for the present method described herein, and vice versa. Where the various embodiments and advantages have already been described above and in the examples section further hereinbelow, they shall not be iterated for brevity.

20 [0035] The method for forming the ceramic core, e.g., the water-soluble ceramic core, described in various aspects and embodiments of the present disclosure, may include providing a slurry mixture comprising the metal oxide, the carbon material, the reinforcement agent, and water, mixing the slurry mixture and the binder, forming a core from the slurry mixture, and curing the core to form the water-soluble ceramic
25 core. In various aspects and embodiments, the carbon material may comprise graphite.

[0036] In various aspects and embodiments, providing the slurry mixture may include mixing the metal oxide, the carbon material, and the reinforcement agent, to form a solid mixture, and mixing the solid mixture and water to form the slurry mixture. Advantageously, a homogeneous slurry mixture helps improve (or at least maintain) the
30 mechanical strength of the water-soluble ceramic core. Mixing aforesaid components to form a slurry mixture confers better homogeneity during mixing. In non-limiting examples, the solid components may be mixed to form the solid mixture, then addition

of water to the solid mixture while mixing the solid mixture. In another non-limiting instances, the slurry mixture may be homogenously formed by adding the components, such as the metal oxide, the carbon material, the reinforcement agent, and water, then mixing may be carried out.

5 [0037] In various aspects and embodiments, mixing the slurry mixture and the binder may include adding the binder to the slurry mixture so as to have the slurry mixture and the binder homogenously mixed. Said differently, the binder may be homogeneously mixed in the slurry mixture. In various aspects and embodiments, mixing the slurry mixture and the binder may include dissolving the binder in water to form a binder
10 solution, and adding the binder solution dropwise to the slurry mixture. Dropwise addition of the binder solution may help in having the binder homogeneously mixed in the slurry mixture. In instances where the amount of binder used is lesser than the slurry mixture, it may be advantageous to add the binder to the slurry mixture instead of adding the slurry mixture to the binder.

15 [0038] In various aspects and embodiments, forming the core may include drying the slurry mixture to form a dried slurry, forming a powder from the dried slurry, and applying pressure to the powder to form the core.

[0039] In various aspects and embodiments, drying the slurry may include heating the slurry mixture at 50°C to 100°C, 60°C to 100°C, 70°C to 100°C, 80°C to 100°C, 90°C
20 to 100°C, etc. In various aspects and embodiments, drying the slurry may include heating the slurry mixture at 70°C. Advantageously, these temperatures, which do not exceed 100°C, reduce the risk of damaging or affecting the binder from conferring mechanical properties (e.g., flexural strength) to the resultant ceramic core.

[0040] In various aspects and embodiments, forming the powder may include crushing
25 the dried slurry.

[0041] In various aspects and embodiments, forming the core may further include packing the powder into a die, and applying the pressure to the powder, wherein the pressure is in a range of 80 MPa to 100 MPa, 90 MPa to 100 MPa, 80 MPa to 90 MPa, etc. These pressures are advantageous in that the pressures are sufficient to impart
30 strength and water-collapseability of the resultant ceramic core, without damaging the resultant ceramic core. The pressure may be applied by an uniaxial exertion of force

(e.g., pressing) on the powder. The die may be configured to confer the core one or more of the shapes mentioned above.

[0042] In various aspects and embodiments, curing the core may include heating the core at a temperature range of 150°C to 250°C, 200°C to 250°C, 150°C to 200°C, etc.

5 **[0043]** The present disclosure describes an investment casting method. Embodiments and advantages described for the ceramic core and the method for forming the ceramic core of various aspects of the present disclosure can be analogously valid for the present investment casting method described herein, and vice versa. Where the various embodiments and advantages have already been described above and in the examples
10 section further hereinbelow, they shall not be iterated for brevity.

[0044] The investment casting method may include providing the water-soluble ceramic core described in various aspects and embodiments of the present disclosure, heating the water-soluble ceramic core to a first temperature, and heating the water-soluble ceramic core from the first temperature to a second temperature, wherein the
15 first temperature is lower than the second temperature. The second temperature prepares the water-soluble ceramic core for investment casting, wherein the water-soluble may be contacted with a molten metal when the molten metal is poured into a mold containing the water-soluble ceramic core.

[0045] In various aspects and embodiments, heating the water-soluble ceramic core to
20 the first temperature (i.e., a first stage heating) may include heating the water-soluble ceramic core to a temperature of 450°C to 550°C, 500°C to 550°C, 450°C to 500°C, 500°C, etc. The first stage heating may be called a “pre-heating step” (or “pre-heating” for brevity) in the present disclosure. Advantageously, such first stage heating helps reduce thermal shock to the water-soluble ceramic core, as such temperatures render
25 the water-soluble ceramic core at a higher temperature (compared to ambient room temperature) before the water-soluble ceramic core gets heated to the second temperature. If the water-soluble ceramic core is heated directly to the second temperature without first heating to the first temperature, the water-soluble ceramic core may suffer from thermal stress that may damage the water-soluble ceramic core (e.g.,
30 crack, delaminate), the damage may become even more pronounced during investment casting, wherein the investment casting may be carried out at the second temperature or higher.

[0046] In various aspects and embodiments, heating the water-soluble ceramic core from the first temperature to the second temperature (for the investment casting) may include heating the water-soluble ceramic core to a temperature of 1000°C to 1200°C, 1100°C to 1200°, 1000°C to 1100°C, etc., from the first temperature. Advantageously, heating to such temperatures (i.e., the second temperatures) from the first temperature helps reduce thermal shock to the water-soluble ceramic core when the water-soluble ceramic core contacts an even hotter molten metal, as such temperatures render the water-soluble ceramic core at a temperature closer to the molten metal or closer to the temperature used during investment casting. If the water-soluble ceramic core comes directly into contact with a molten metal (without being heated to the first temperature and then heated the second temperature), the water-soluble ceramic core may suffer from thermal stress that may damage the water-soluble ceramic core (e.g., crack, delaminate), the damage may become even more pronounced during investment casting, wherein the investment casting may be carried out at the second temperature or higher.

[0047] In various aspects and embodiments, the investment casting method may further include pausing the heating at the first temperature (e.g., 450°C to 550°C) for a duration (e.g., 3 hours to 5 hours), before heating the water-soluble ceramic core from the first temperature to the second temperature. Said differently, in various aspects and embodiments, the investment casting method may further include maintaining the first temperature for a duration of 3 hours to 5 hours, 4 hours to 5 hours, 3 hours to 4 hours, 4 hours, etc., after the water-soluble ceramic core reaches the first temperature, but prior to heating the water-soluble ceramic core to the second temperature from the first temperature. Advantageously, maintaining the first temperature for such a duration helps reduce thermal shock to the water-soluble ceramic core, as such a duration renders the water-soluble ceramic core at a higher temperature (compared to ambient room temperature) before the water-soluble ceramic core gets heated to the second temperature. Such a duration allows the entire water-soluble ceramic core to reach the first temperature (eliminate uneven heating). If the water-soluble ceramic core is heated directly to the second temperature without first maintaining at the first temperature, the water-soluble ceramic core may suffer from thermal stress that may damage the water-soluble ceramic core, the damage may become even more prominent during investment casting (which may be carried out at the second temperature or higher).

[0048] The word “substantially” does not exclude “completely” e.g. a composition which is “substantially free” from Y may be completely free from Y. Where necessary, the word “substantially” may be omitted from the definition of the present disclosure.

5 [0049] In the context of various embodiments, the articles “a”, “an” and “the” as used with regard to a feature or element include a reference to one or more of the features or elements.

[0050] In the context of various embodiments, the term “about” or “approximately” as applied to a numeric value encompasses the exact value and a reasonable variance.

10 [0051] As used herein, the term “and/or” includes any and all combinations of one or more of the associated listed items.

[0052] Unless specified otherwise, the terms “comprising” and “comprise”, and grammatical variants thereof, are intended to represent “open” or “inclusive” language such that they include recited elements but also permit inclusion of additional, unrecited elements.

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Examples

[0053] The present disclosure relates to a ceramic core, and a method for forming the ceramic core. The present disclosure relates to an investment casting method involving the ceramic core. Advantageously, the ceramic core (and the method for forming the ceramic core) are able to maintain its structural integrity even at traditional high temperatures used in traditional investment casting. In other words, the ceramic core has enhanced high temperature structural integrity (i.e., high temperature resistance) even under investment casting. Also, even with the considerably improved temperature resistance, ease of removal of the ceramic core after investment casting is not compromised.

20 [0054] The present ceramic core, method for forming the ceramic core, and the investment casting method, are described in further details, by way of non-limiting examples, as set forth below.

[0055] Example 1: Preparation of ceramic slurry

30 [0056] The following materials are non-limiting examples for demonstrating a ceramic core of the present disclosure.

[0057] Magnesium oxide, MgO (99%, Merck), graphite (99%, Merck), kaolinite (natural, Merck) and magnesium sulfate heptahydrate, $\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$ (Bioultra, Merck) are used in a weight ratio 24:24:1:1.

5 [0058] 11.025 g MgO, 11.025 g graphite and 2.535 g kaolinite are mixed with a mixer at 500 rpm until a homogeneous solid mixture is obtained. 24 ml of deionized water is then added to the solid mixture and stirred constantly to create a slurry-like mixture. 0.415 g of $\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$ was then dissolved in 4 ml of deionized water and this solution was added dropwise to the slurry while stirring for homogenous mixing. The slurry was then dried in an oven at 50°C to 100°C (e.g., 70°C) overnight.

10 [0059] The above materials were used to demonstrate a non-limiting examples of a ceramic core of the present disclosure. Apart from magnesium oxide, other materials used include calcium oxide, barium oxide, etc. Apart from kaolinite, boron carbide, silicon carbide, aluminum oxide, and silicon dioxide, were used as the reinforcement agent. Apart from magnesium sulfate, other materials used as the binder include
15 potassium carbonate, starch, and polyacrylic acid.

[0060] In various non-limiting examples, the metal oxide, the carbon material comprising the graphite, the reinforcement agent, and the binder, are mixed in a weight ratio of 24:24:1:1. Other weight ratios were experimented and used.

[0061] Example 2: Preparation of rectangular shaped core

20 [0062] The dried slurry was crushed into powder with an agate mortar and the powders were subsequently packed into 40 mm x 10 mm die and pressed with of 80 MPa to 100 MPa of pressure (e.g., 98 MPa, 4-ton force over 400 mm²) for at least 5 minutes.

[0063] Lastly, the ceramic sample was cured in the oven at 150°C to 250°C (e.g., 200°C) for about 3 hours in air to obtain a black rectangular ceramic block (see FIG.
25 2). The ceramic block is exchangeably referred to as a “ceramic core” in the present disclosure.

[0064] Example 3: High temperature heat treatment regime (Pre-heating in investment casting)

30 [0065] A heat treatment regime was developed for the investment casting, as shown in FIG. 3. For the investment casting method, a holding time of 3 hours to 5 hours (e.g., 4 hours) at 450°C to 550°C (e.g., 500°C) (first temperature) was incorporated to allow any residual stress in the ceramic core to dissipate, reducing the possibility of

delamination at higher temperatures. This holding step in the present investment casting method may be referred to, in the present disclosure, as a “pre-heating” step. The core, which was subjected to such heat treatment regime in an investment casting method of the present disclosure, can be seen in FIG. 4. No significant cracks or delamination was observed in the core sample (even after heating to higher temperatures, e.g., second temperature of 1000°C to 1200°C).

[0066] Example 4: Flexural stress testing after heat treatment regime

[0067] The flexural stress of the ceramic samples pressed at different compact pressures were tested via the fourpoint flexural test using an Instron 5900R with a flexural span of 10 mm, a load cell of 100 N and rate of 0.5 mm/min. FIG. 5 shows the flexural strength of several ceramic samples with different binder (MgSO_4) and reinforcement agent (kaolinite) concentrations.

[0068] Example 5: Comparison of traditional ceramic core and ceramic core of the present disclosure

[0069] As can be seen from FIG. 6, ceramic cores of the present disclosure has an improved formulation that confers greater flexural strength both before and after the investment casting method (with the heat treatment regime) at 1050°C. In addition to the enhanced structural integrity, ceramic cores of the present disclosure suffers from less dimensional shrinkage and still has the ability to readily collapse in water upon sonication and external pressure. The ceramic cores of the present disclosure may collapsed after sonication and with gentle prodding, demonstrating its ease of removal by water is not compromised.

[0070] While the present disclosure has been particularly shown and described with reference to specific embodiments, it should be understood by those skilled in the art that various changes in form and detail may be made therein without departing from the spirit and scope of the present disclosure as defined by the appended claims. The scope of the present disclosure is thus indicated by the appended claims and all changes which come within the meaning and range of equivalency of the claims are therefore intended to be embraced.

CLAIMS

1. A water-soluble ceramic core comprising:
a metal oxide comprising an alkaline earth metal;
5 a carbon material comprising graphite;
a reinforcement agent; and
a binder.
2. The water-soluble ceramic core of claim 1, wherein the metal oxide comprises
10 magnesium oxide, calcium oxide, or barium oxide.
3. The water-soluble ceramic core of claim 1 or 2, wherein the carbon material
consists of graphite.
- 15 4. The water-soluble ceramic core of any one of claims 1 to 3, wherein the
reinforcement agent comprises kaolinite, boron carbide, silicon carbide, aluminum
oxide, or silicon dioxide.
5. The water-soluble ceramic core of any one of claims 1 to 4, wherein the binder
comprises magnesium sulfate, potassium carbonate, starch, or polyacrylic acid.
6. The water-soluble ceramic core of any one of claims 1 to 5, wherein the metal
oxide, the carbon material, the reinforcement agent, and the binder, are mixed in a
20 weight ratio of 24:24:1:1.
7. A method for forming the water-soluble ceramic core of any one of claims 1 to
6, the method comprising:
providing a slurry mixture comprising the metal oxide, the carbon material, the
reinforcement agent, and water, wherein the carbon material comprises graphite;
mixing the slurry mixture and the binder;
forming a core from the slurry mixture; and
curing the core to form the water-soluble ceramic core.

8. The method of claim 7, wherein providing the slurry mixture comprises:
mixing the metal oxide, the carbon material, and the reinforcement agent, to form a solid mixture; and
mixing the solid mixture and water to form the slurry mixture.
9. The method of claim 7 or 8, wherein mixing the slurry mixture and the binder comprises:
dissolving the binder in water to form a binder solution; and
adding the binder solution dropwise to the slurry mixture.
10. The method of any one of claims 7 to 9, wherein forming the core comprises:
drying the slurry mixture to form a dried slurry;
forming a powder from the dried slurry; and
applying pressure to the powder to form the core.
11. The method of claim 10, wherein drying the slurry comprises heating the slurry mixture at a temperature range of 50°C to 100°C.
12. The method of claim 10 or 11, wherein forming the powder comprises crushing the dried slurry.
13. The method of any one of claims 10 to 12, wherein forming the core further comprises:
packing the powder into a die; and
applying the pressure to the powder, wherein the pressure is in a range of 80 MPa to 100 MPa.
14. The method of any one of claims 7 to 13, wherein curing the core comprises heating the core at a temperature range of 150°C to 250°C.

15. An investment casting method comprising:
providing the water-soluble ceramic core of any one of claims 1 to 6;
heating the water-soluble ceramic core to a first temperature; and
heating the water-soluble ceramic core from the first temperature to a second temperature, wherein the first temperature is lower than the second temperature.
16. The investment casting method of claim 15, wherein heating the water-soluble ceramic core to the first temperature comprises heating the water-soluble ceramic core to a temperature of 450°C to 550°C.
17. The investment casting method of claim 15 or 16, wherein heating the water-soluble ceramic core from the first temperature to the second temperature comprises heating the water-soluble ceramic core to a temperature of 1000°C to 1200°C from the first temperature.
18. The investment casting method of any one of claims 15 to 17, further comprising:
maintaining the first temperature for a duration of 3 hours to 5 hours, after the water-soluble ceramic core reaches the first temperature, but prior to heating the water-soluble ceramic core to the second temperature from the first temperature.