US 20230059113A1

(19) United States
(12) Patent Application Publication
(10) Pub. No.: US 2023/0059113 A1
Yang et al.
(43) Pub. Date: Feb. 23, 2023

(54) CAST STEEL ALLOY COMPONENT HAVING REDUCED FERRITE AND ENHANCED ULTIMATE TENSILE STRENGTH FOR A VEHICLE

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(21) Appl. No.: **17/407,884**

(22) Filed: **Aug. 20, 2021**

Publication Classification

(51) Int. Cl.

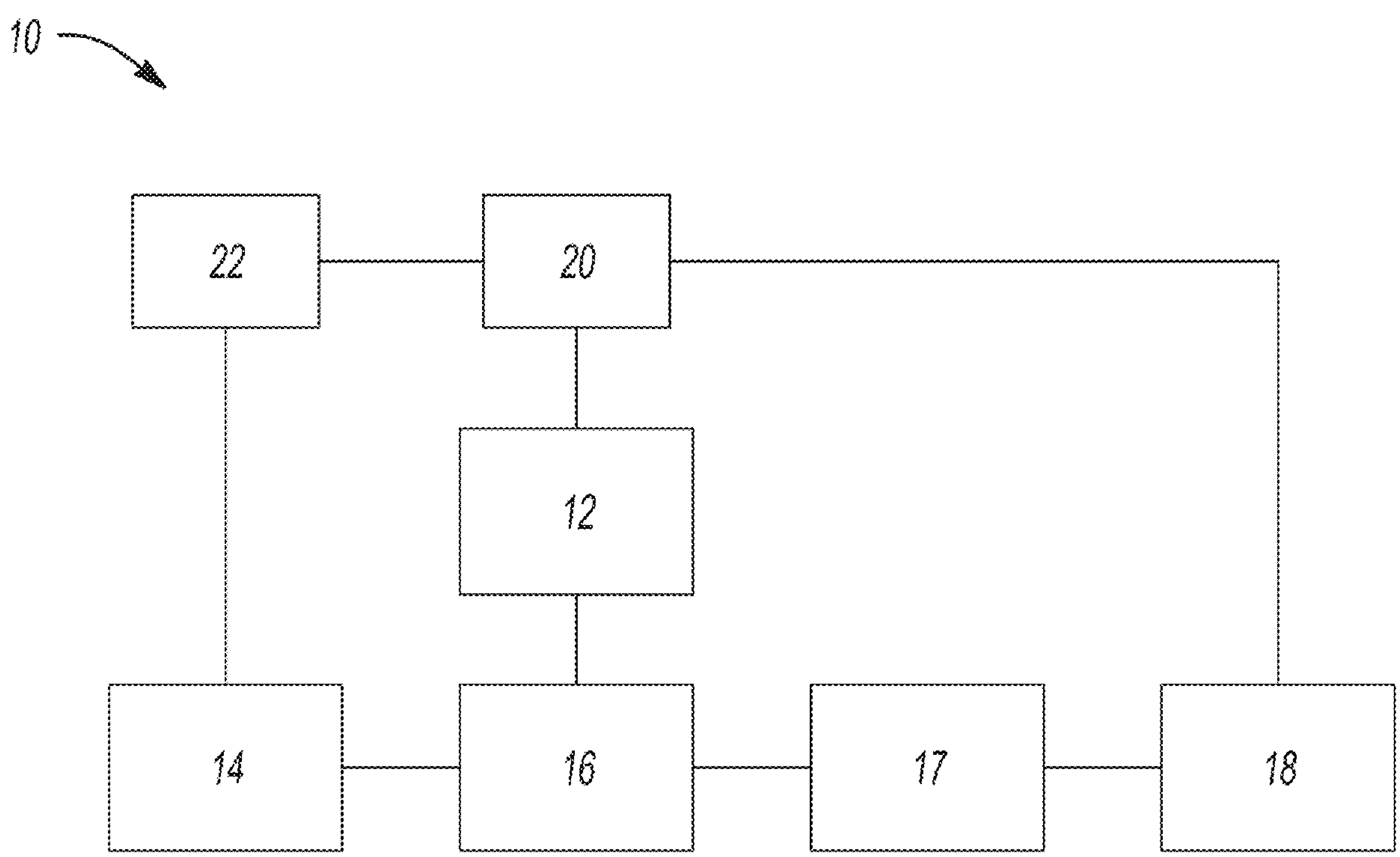
B22D 29/04	(2006.01)
C22C 38/44	(2006.01)
C22C 38/42	(2006.01)
C22C 38/50	(2006.01)
C22C 38/46	(2006.01)
C22C 38/02	(2006.01)
C22C 38/04	(2006.01)
C22C 38/06	(2006.01)
C22C 38/00	(2006.01)

(52) U.S. Cl.

CPC ***B22D 29/04*** (2013.01); ***C22C 38/44*** (2013.01); ***C22C 38/42*** (2013.01); ***C22C 38/50*** (2013.01); ***C22C 38/46*** (2013.01); ***C22C 38/02*** (2013.01); ***C22C 38/04*** (2013.01); ***C22C 38/06*** (2013.01); ***C22C 38/001*** (2013.01); ***C22C 38/005*** (2013.01); *C21D 2211/005* (2013.01)

(57) **ABSTRACT**

A cast steel alloy for an engine of a vehicle is provided. The cast steel alloy comprises 0.29 to 0.65 weight percent (wt %) carbon, 0.40 to 0.80 wt % silicon, 0.6 to 1.5 wt % manganese, up to 0.03 wt % phosphorus, 0.04 to 0.07 wt % sulfur, 0.8 to 1.4 wt % chromium, 0.2 to 0.6 wt % nickel, 0.15 to 0.55 wt % molybdenum, 0.25 to 2.0 wt % copper, up to 0.03 wt % titanium, 0.07 to 0.17 wt % vanadium, 0.02 to 0.06 wt % aluminum, up to 0.03 wt % nitrogen (N), and 0.01 to 0.06 wt % of at least one of cerium (Ce) and lanthanum. The cast steel alloy has unexpected and unconventional results such as reduced ferrite and enhanced strengths.



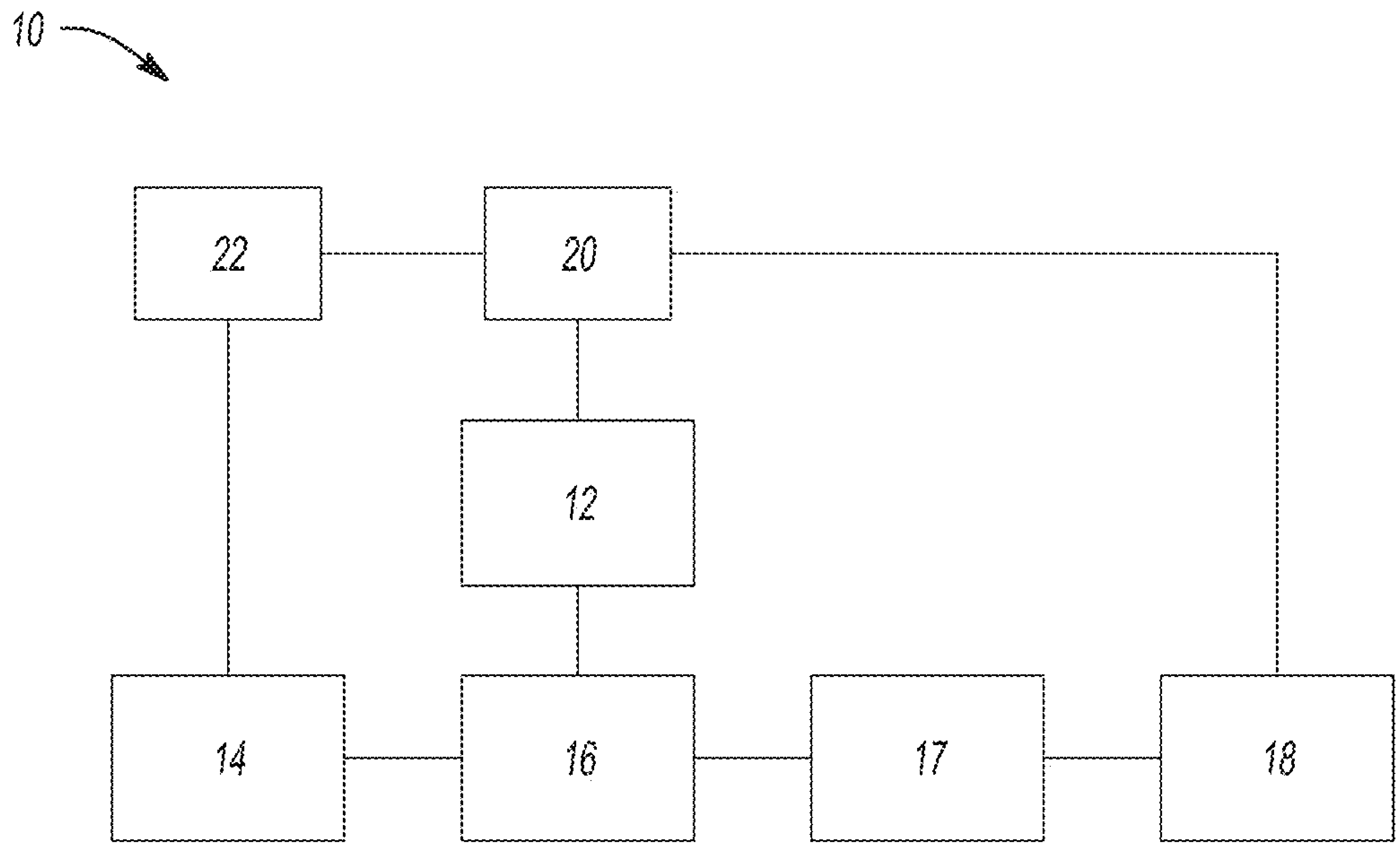


FIG. 1

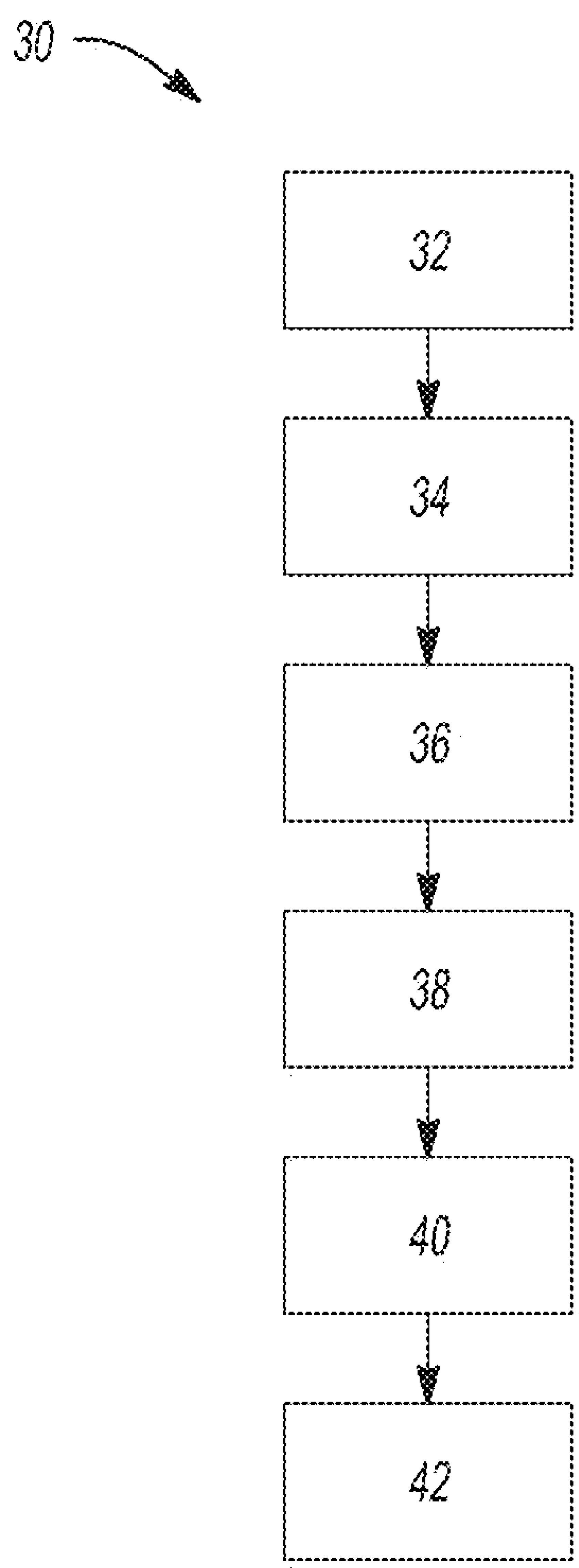


FIG. 2

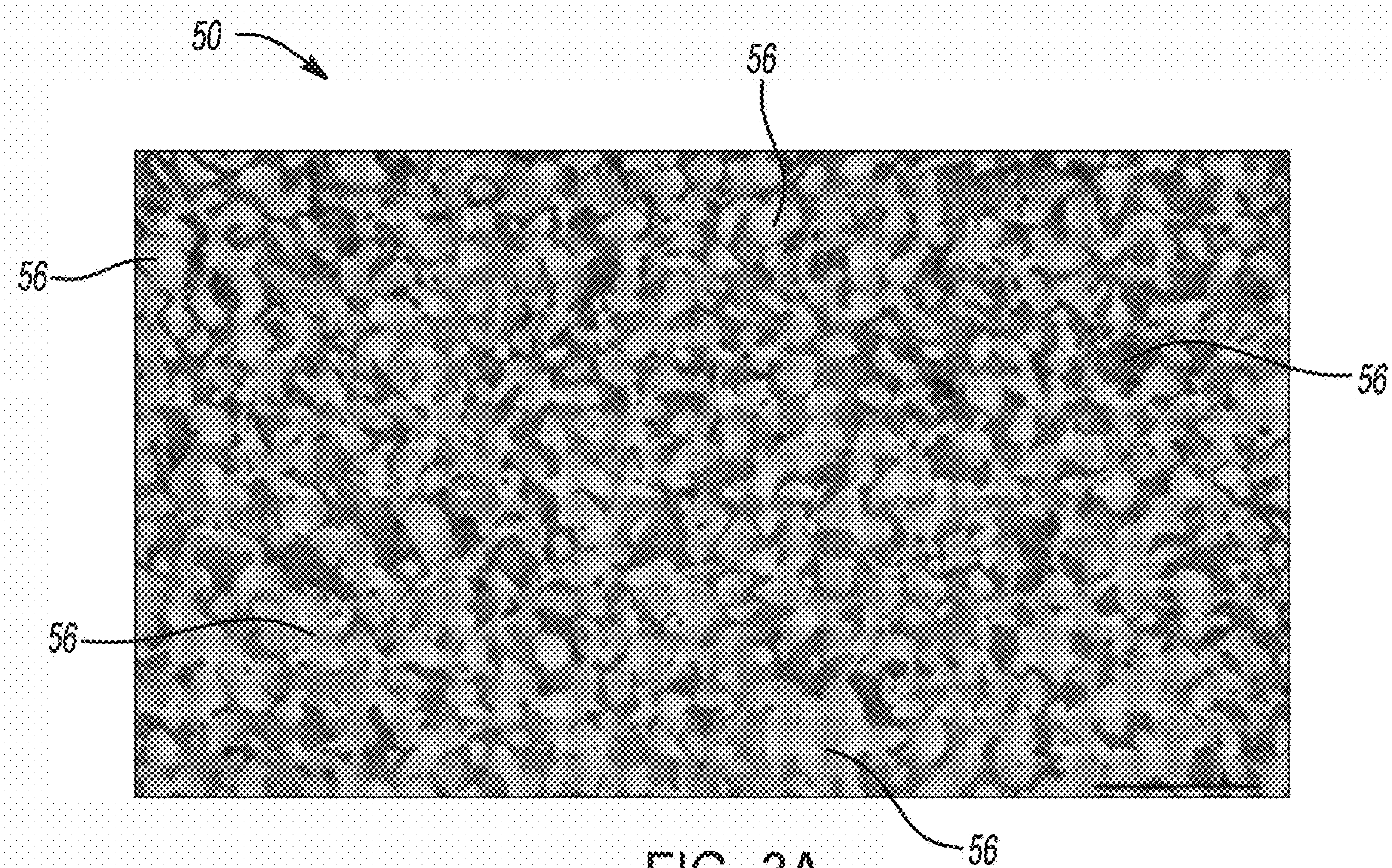


FIG. 3A

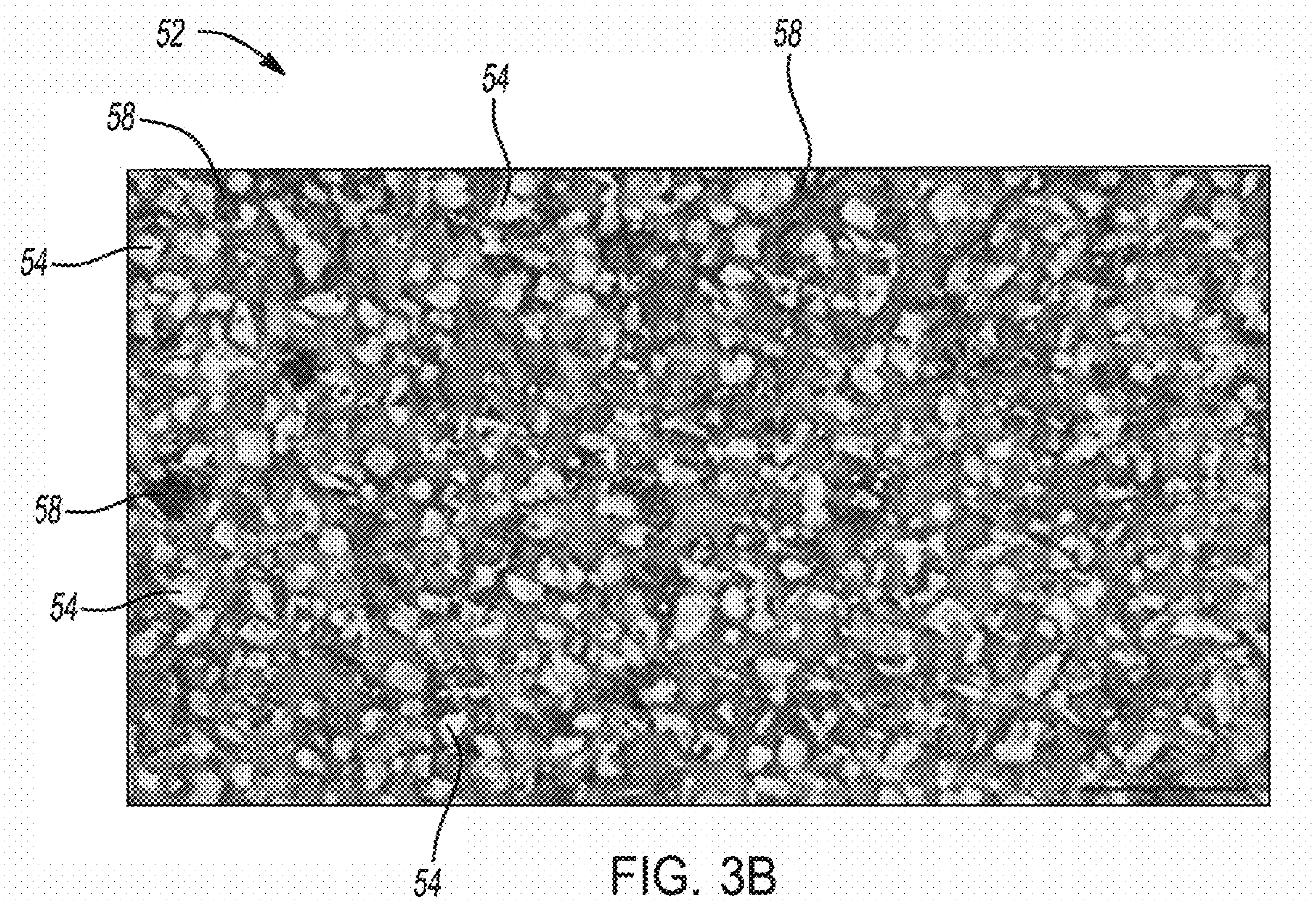


FIG. 3B

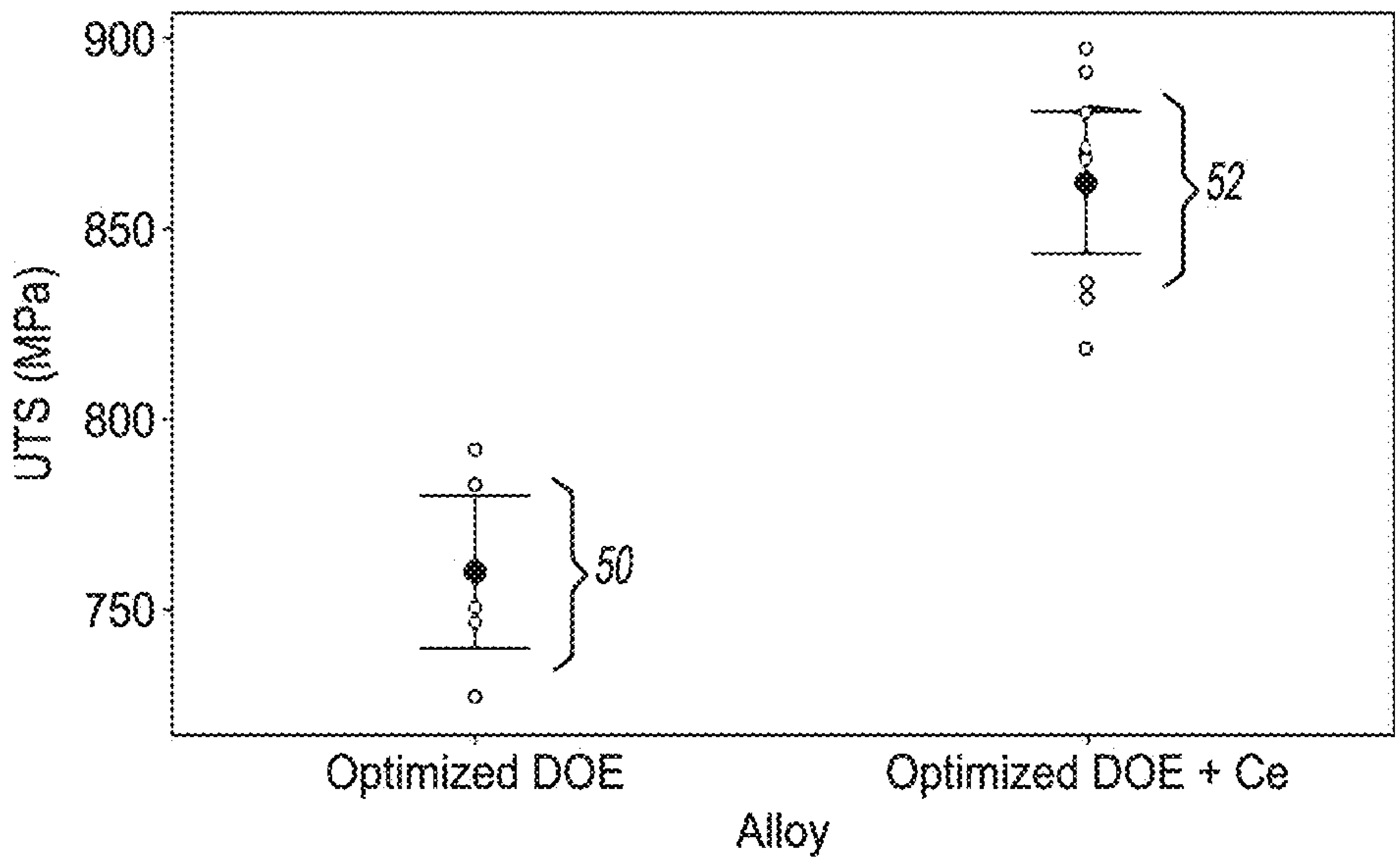

900
850
800
750
UTS (MPa)
52
50
Optimized DOE
Optimized DOE + Ce
Alloy

FIG. 4

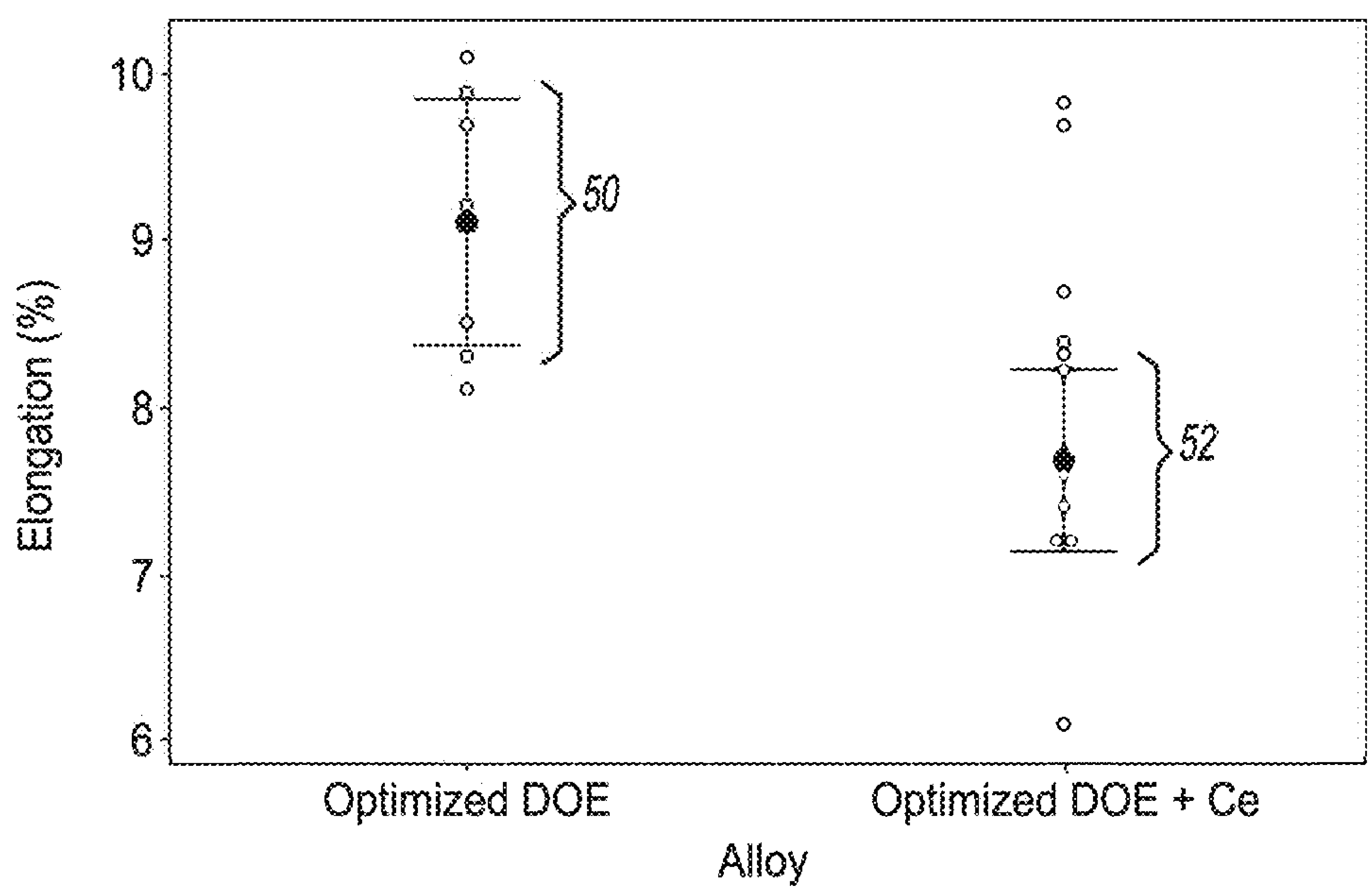

10
9
8
7
6
Elongation (%)
50
52
Optimized DOE
Optimized DOE + Ce
Alloy

FIG. 5

CAST STEEL ALLOY COMPONENT HAVING REDUCED FERRITE AND ENHANCED ULTIMATE TENSILE STRENGTH FOR A VEHICLE

GOVERNMENT FUNDING

[0001] This invention was made with government support under reference number DE-EE0008877, LMHE awarded by the Department of Energy.

INTRODUCTION

[0002] The present disclosure relates to steel alloys and, more particularly, systems and methods of casting steel alloys with rare earth alloying elements such as cerium and lanthanum for vehicle components.

[0003] Steel alloys may be used in components of vehicles. In many situations, quench and temper heat treatments are performed on steel alloys. However, processing costs of quench and temper heat treatments are expensive. Residual stress can also be generated during heat treatment causing issues of parts prematurely cracking.

SUMMARY

[0004] Thus, while current systems and methods to make steel components achieve their intended purpose, there is a need for a new and improved system and method for making steel alloy components, e.g., crankshafts, for vehicles.

[0005] Accordingly, a cast steel component for a vehicle, a method of casting a steel alloy, and a system for casting the steel alloy are provided as aspects of the present disclosure. In accordance with one aspect of the present disclosure, a method of casting a steel alloy having reduced ferrite and enhanced ultimate tensile strength for a component of an engine is provided. The method comprises providing a mold of the component. The mold has at least one molded cavity. The method further comprises melting a steel alloy at between 1620 degrees Celsius (° C.) and 1700° C. The steel alloy comprises at least one of carbon (C), silicon (Si), manganese (Mn), phosphorus (P), sulfur (S), chromium (Cr), nickel (Ni), molybdenum (Mo), copper (Cu), titanium (Ti), vanadium (V), aluminum (Al), and nitrogen (N), defining a raw charge.

[0006] In this aspect, the method further comprises adding master alloy solutes to the raw charge at between 1620° C. and 1700° C. to define the steel melt. The steel melt solution comprises greater than 0.29 weight percent (wt %) C, greater than 0.40 wt % Si, greater than 0.6 wt % Mn, up to 0.03 wt % P, greater than 0.04 wt % S, greater than 0.8 wt % Cr, about 0.2 wt % Ni, greater than 0.15 wt % Mo, greater than 0.25 wt % Cu, up to 0.03 wt % Ti, greater than 0.07 wt % V, greater than 0.02 wt % Al, up to 0.03 wt % N, and 0.01 to 0.06 wt % of at least one of cerium (Ce) and lanthanum (La). Moreover, the steel melt has a target composition of 0.35 wt % C, 0.45 wt % Si, 1.0 wt % Mn, up to 0.03 wt % P, 0.06 wt % S, 1.0 wt % Cr, 0.2 wt % Ni, 0.25 wt % Mo, 0.45 wt % Cu, up to 0.03 wt % Ti, 0.1 wt % V, 0.03 wt % Al, 0.03 wt % N, and 0.02 wt % of at least one of Ce and La.

[0007] In this aspect, the method further comprises pouring the steel melt in the at least one molded cavity at about 1600° C., cooling and solidifying the target steel alloy in the at least one molded cavity till about 450° C. The method further comprises separating the target steel alloy from the at least one molded cavity defining a cast steel component having reduced ferrite and enhanced strengths.

[0008] In one example of this aspect, the steel melt comprises 0.02 wt % of La and Ce and has a La—Ce weight ratio of greater than 2:1. In another example, the steel melt comprises 0.02 wt % of Ce and La and has a Ce—La weight ratio of greater than 2:1. In yet another example, the cast steel component has an ultimate tensile strength of about 840 MPa and about 1100 MPa. In still another example, the cast steel component has an elongation percent of between about 7% and about 10%

[0009] In another example, the step of separating comprises shaking out the at least one molded cavity from target steel alloy and degating the target steel alloy casting after the step of shaking out. The step of separating further comprises cleaning the target steel alloy after the step of degating and inspecting the target steel alloy after the step of cleaning to define the cast steel component.

[0010] In yet another example, the step of providing comprises making the mold of the component, the mold having a pattern with dimensions identical to the cast steel component.

[0011] In accordance with another aspect of the present disclosure, a system for casting a steel alloy having reduced ferrite and enhanced ultimate tensile strength for a component of an engine is provided. In this aspect, the system comprises a molding unit for making a mold of the component having at least one molded cavity. The system further comprises a furnace for melting a steel raw charge solution and master alloy solutes at between 1620 degrees Celsius (° C.) and 1700° C. to define a steel melt. In this example, the steel melt solution comprises at least one of carbon (C), silicon (Si), manganese (Mn), phosphorus (P), sulfur (S), chromium (Cr), nickel (Ni), molybdenum (Mo), copper (Cu), titanium (Ti), vanadium (V), aluminum (Al), and nitrogen (N). The steel melt solution comprises greater than 0.29 weight percent (wt %) C, greater than 0.40 wt % Si, greater than 0.6 wt % Mn, up to 0.03 wt % P, greater than 0.04 wt % S, greater than 0.8 wt % Cr, about 0.2 wt % Ni, greater than 0.15 wt % Mo, greater than 0.25 wt % Cu, up to 0.03 wt % Ti, greater than 0.07 wt % V, greater than 0.02 wt % Al, up to 0.03 wt % N, and 0.01 to 0.06 wt % of at least one of cerium (Ce) and lanthanum (La).

[0012] In this aspect, the steel melt has a composition of 0.29 to 0.65 weight percent (wt %) carbon, 0.40 to 0.80 wt % silicon, 0.6 to 1.5 wt % manganese, up to 0.03 wt % phosphorus, 0.04 to 0.07 wt % sulfur, 0.8 to 1.4 wt % chromium, 0.2 to 0.6 wt % nickel, 0.15 to 0.55 wt % molybdenum, 0.25 to 2.0 wt % copper, up to 0.03 wt % titanium, 0.07 to 0.17 wt % vanadium, 0.02 to 0.06 wt % aluminum, up to 0.03 wt % nitrogen (N), and 0.01 to 0.06 wt % of at least one of cerium (Ce) and lanthanum.

[0013] In this aspect, the system comprises a pouring mechanism for pouring the steel melt in the at least one molded cavity at about 1600° C. and a cooling area or station for solidifying the cast steel alloy in the at least one molded cavity at about 450° C. Moreover, the system comprises a separation unit for separating the cast steel alloy from the at least one molded cavity defining a cast steel component having reduced ferrite and enhanced ultimate tensile strength. Additionally, the system comprises a controller in communication with the molding unit, the furnace, the pouring mechanism, and the shakeout unit. The controller is configured to control molding unit, the furnace, the pouring mechanism, and the separation unit. Furthermore, the system comprises a power source configured to power the molding unit, the furnace, the pouring mechanism, the separation unit, and the controller.

[0014] In one embodiment, the steel melt comprises 0.02 wt % of La and Ce, the steel melt having a La—Ce weight ratio of greater than 2:1. In another embodiment, the steel melt comprises 0.02 wt % of Ce or La, the steel melt having a Ce—La weight ratio of greater than 2:1. In yet another embodiment, the cast steel component has an ultimate tensile strength of about 840 MPa and about 1100 MPa. In still another embodiment, the cast steel component has an elongation percent of between about 7% and about 10%.

[0015] In another embodiment, the separation unit is arranged to shakeout the at least one molded cavity from target steel alloy, degate the target steel alloy after shaking out the at least one molded cavity, clean the target steel alloy casting after degating the target steel alloy, and inspect the target steel alloy casting after the cleaning the target steel alloy, defining the cast steel component.

[0016] In yet another embodiment, the steel melt has a target composition of 0.35 wt % C, 0.45 wt % Si, 1.0 wt % Mn, up to 0.03 wt % P, 0.06 wt % S, 1.0 wt % Cr, 0.2 wt % Ni, 0.25 wt % Mo, 0.45 wt % Cu, up to 0.03 wt % Ti, 0.1 wt % V, 0.03 wt % Al, 0.03 wt % N, and 0.02 wt % of at least one of Ce and La.

[0017] In another aspect of the present disclosure, a steel alloy for a vehicle. The steel alloy has reduced ferrite and enhanced strengths. The steel alloy comprises 0.29 to 0.65 weight percent (wt %) carbon (C), 0.40 to 0.80 wt % silicon (Si), 0.6 to 1.5 wt % manganese (Mn), up to 0.03 wt % phosphorus (P), 0.04 to 0.07 wt % sulfur (S), 0.8 to 1.4 wt % chromium (Cr), 0.2 to 0.6 wt % nickel (Ni), 0.15 to 0.55 wt % molybdenum (Mo), 0.25 to 2.0 wt % copper (Cu), up to 0.03 wt % titanium (Ti), 0.07 to 0.17 wt % vanadium (V), 0.02 to 0.06 wt % aluminum (Al), up to 0.03 wt % nitrogen (N), and 0.01 to 0.06 wt % of at least one of cerium (Ce) and lanthanum (La).

[0018] In one embodiment of this aspect, the steel alloy comprises:0.35 wt % C, 0.45 wt % Si, 1.0 wt % Mn, up to 0.03 wt % P, 0.06 wt % S, 1.0 wt % Cr, 0.2 wt % Ni, 0.25 wt % Mo, 0.45 wt % Cu, up to 0.03 wt % Ti, 0.1 wt % V, 0.03 wt % Al, 0.03 wt % N, and 0.02 wt % of at least one of Ce and La. In another embodiment, the steel alloy has a La—Ce weight ratio of greater than 2:1. In yet another embodiment, the steel alloy has a Ce—La weight ratio of greater than 2:1. In still another embodiment, the steel alloy has an ultimate tensile strength of about 840 MPa and about 1100 MPa. Furthermore, the steel alloy is formed of a cast steel component for a vehicle such as a crankshaft.

[0019] Further areas of applicability will become apparent from the description provided herein. It should be understood that the description and specific examples are intended for purposes of illustration only and are not intended to limit the scope of the present disclosure.

BRIEF DESCRIPTION OF THE DRAWINGS

[0020] The drawings described herein are for illustration purposes only and are not intended to limit the scope of the present disclosure in any way.

[0021] FIG. **1** is a schematic view of a system for casting a steel alloy having reduced ferrite and enhanced strengths for a component of an engine in accordance with one embodiment of the present disclosure.

[0022] FIG. **2** is a flowchart of a method of casting the steel alloy with cerium by system in FIG. **1** in accordance with one example of the present disclosure.

[0023] FIG. **3**A is a metallographic image of a cross-sectional view of the cast steel alloy without cerium from the system of FIG. **1**.

[0024] FIG. **3**B is a metallographic image of a cross-sectional view of a cast steel alloy with cerium from the system of FIG. **1**.

[0025] FIG. **4** is an ultimate tensile strength versus graph of cast steel alloys by the system in FIG. **1**.

[0026] FIG. **5** is a total elongation versus alloy graph of cast steel alloys by the system in FIG. **1**.

DETAILED DESCRIPTION

[0027] The following description is merely exemplary in nature and is not intended to limit the present disclosure, application, or uses.

[0028] The present disclosure provides a cast steel component, e.g., a crankshaft, for a vehicle wherein the cast steel component comprises 0.01 to 0.06 weight percent of at least one of cerium and lanthanum. Moreover, the present disclosure provides methods and systems for casting the steel component. Due to the content of cerium or lanthanum, the cast steel component has shown to have unexpected results of reduced ferrite and enhanced strengths. For example, Such strengths that are enhanced include yield strength, ultimate strength, and fatigue strength.

[0029] In accordance with one embodiment of the present disclosure, FIG. **1** depicts a system **10** for casting a steel alloy having reduced ferrite and enhanced ultimate tensile strength for a component of an engine. As shown, the system **10** comprises a molding unit **12** for making a mold of the component having at least one molded cavity, preferably a plurality of molded cavities, to define the component to be cast. The molding unit **12** is arranged to make the mold having a pattern (not shown) with dimensions the same as the component to be cast. In one example, the mold has patterns made with green or chemically bonded sand. An assembly of core may then be disposed within the mold to further define the dimensions or structure of the pattern. It is to be understood that the mold may be made by any other suitable manner without departing from the spirit or scope of the present disclosure.

[0030] The system **10** further comprises a furnace **14** for melting a steel charge solution and several master alloy solutes at between 1620 degrees Celsius (° C.) and 1700° C., preferably 1650° C. to define a steel melt. In one embodiment, the furnace **14** may be charged with the steel solvent such as scrap steel as raw materials. The furnace **14** may be an electric arc furnace, an induction furnace, or any other suitable furnace without departing from the spirit or scope of the present disclosure. In this embodiment, the steel solvent comprises at least one of carbon (C), silicon (Si), manganese (Mn), phosphorus (P), sulfur (S), chromium (Cr), nickel (Ni), molybdenum (Mo), copper (Cu), titanium (Ti), vanadium (V), aluminum (Al), and nitrogen (N).

[0031] In this embodiment, the steel solution may then be alloyed in the furnace **14** by adding the master alloy solutes. In a preferred embodiment, the master alloy solute comprises greater than 0.29 weight percent (wt %) C, greater than 0.40 wt % Si, greater than 0.6 wt % Mn, up to 0.03 wt % P, greater than 0.04 wt % S, greater than 0.8 wt % Cr, about 0.2 wt % Ni, greater than 0.15 wt % Mo, greater than

0.25 wt % Cu, up to 0.03 wt % Ti, greater than 0.07 wt % V, greater than 0.02 wt % Al, up to 0.03 wt % N, and 0.01 to 0.06 wt % of at least one of cerium (Ce) and lanthanum (La). As will be described in greater detail below, the addition of 0.01 to 0.06 wt % of the at least one of Ce and La provides unexpected results of reduced ferrite and enhanced ultimate tensile strength to the component to be cast.

[0032] In a preferred embodiment, the steel melt, and hence the component, has a target composition of 0.29 to 0.65 weight percent (wt %) carbon, 0.40 to 0.80 wt % silicon, 0.6 to 1.5 wt % manganese, up to 0.03 wt % phosphorus, 0.04 to 0.07 wt % sulfur, 0.8 to 1.4 wt % chromium, 0.2 to 0.6 wt % nickel, 0.15 to 0.55 wt % molybdenum, 0.25 to 2.0 wt % copper, up to 0.03 wt % titanium, 0.07 to 0.17 wt % vanadium, 0.02 to 0.06 wt % aluminum, up to 0.03 wt % nitrogen (N), and 0.01 to 0.06 wt % of at least one of cerium (Ce) and lanthanum.

[0033] In a more preferred embodiment, the steel melt has a target composition of 0.35 wt % C, 0.45 wt % Si, 1.0 wt % Mn, up to 0.03 wt % P, 0.06 wt % S, 1.0 wt % Cr, 0.2 wt % Ni, 0.25 wt % Mo, 0.45 wt % Cu, up to 0.03 wt % Ti, 0.1 wt % V, 0.03 wt % Al, 0.03 wt % N, and 0.02 wt % of at least one of Ce and La.

[0034] In one embodiment, the steel melt comprises 0.02 wt % of La and Ce. In one example, the steel melt has a La—Ce weight ratio of at least 2:1. In another example, the steel melt has a Ce—La weight ratio of at least 2:1.

[0035] Referring to FIG. **1**, the system **10** further comprises a pouring mechanism **16** for pouring the steel melt in the plurality of molded cavities at about 1600° C., defining the dimensions of the component to be cast. In one example, the pouring mechanism **16** may be a pouring ladle. In this example, the pouring ladle receives the master alloy solute which is then added to the steel solution, defining the steel melt. The mold may then be gated or sealed with chemically bonded sand.

[0036] After the master alloy solutes are added to the steel solution, the steel melt is allowed to cool to about 450° C. in a designated cooling area **17** solidify the steel melt (in the plurality of molded cavities of the mold) to form a target steel casting. The steel casting has a composition of 0.29 to 0.65 weight percent (wt %) carbon, 0.40 to 0.80 wt % silicon, 0.6 to 1.5 wt % manganese, up to 0.03 wt % phosphorus, 0.04 to 0.07 wt % sulfur, 0.8 to 1.4 wt % chromium, 0.2 to 0.6 wt % nickel, 0.15 to 0.55 wt % molybdenum, 0.25 to 2.0 wt % copper, up to 0.03 wt % titanium, 0.07 to 0.17 wt % vanadium, 0.02 to 0.06 wt % aluminum, up to 0.03 wt % nitrogen (N), and 0.01 to 0.06 wt % of at least one of cerium (Ce) and lanthanum.

[0037] Preferably, the steel alloy has a target composition of 0.35 wt % C, 0.45 wt % Si, 1.0 wt % Mn, up to 0.03 wt % P, 0.06 wt % S, 1.0 wt % Cr, 0.2 wt % Ni, 0.25 wt % Mo, 0.45 wt % Cu, up to 0.03 wt % Ti, 0.1 wt % V, 0.03 wt % Al, 0.03 wt % N, and 0.02 wt % of at least one of Ce and La.

[0038] As shown in FIG. **1**, the system **10** comprises a separation unit **18** for separating the target steel alloy from the mold having a plurality of molded cavities defining a cast steel component having reduced ferrite and enhanced strengths. In one embodiment, the separation unit **18** is arranged to shakeout or remove the mold comprising the chemically bonded sand from the cast steel component. To accomplish removal of the mold from the cast steel component, an automated unit may be used to break the mold and obtain the cast steel component therefrom. For example, a vibration unit or table may be used having a bottom catch screen for receiving mold particles from the mold. It is to be understood that breaking the mold by any other suitable manner may be used without departing from the spirit or scope of the present disclosure.

[0039] In this embodiment, the separation unit **18** is further arranged to degate the target steel alloy after removing the mold from the cast steel component. As known in the art, degating the target steel alloy may involve removing parts of bonded sand used to fill the mold during casting and gating.

[0040] In this embodiment, the separation unit **18** is further arranged to clean the target steel alloy after degating. In one example, a shot blast machine may be used to apply or shoot steel beads on surfaces of casting with the target steel alloy. To meet alloy design expectations, the separation unit **18** may also include an inspection area wherein the target steel alloy is inspected for its mechanical dimensions, mechanical properties, chemical composition, and microstructure. In one example, a computerized system **10** such as a coordinate measuring machine (CMM) may be used to measure mechanical dimensions of the casting with the target steel alloy, defining the cast steel component. Any suitable methods and apparatus may be used to evaluate dimensions, mechanical properties, chemical composition, and microstructure of the steel alloy without departing from the spirit or scope of the present disclosure.

[0041] In one embodiment, the cast steel component has an unexpected ultimate tensile strength (UTS) of about 840 MPa and about 1100 MPa. In this embodiment, the cast steel component has an unexpected elongation percent of between about 7% and about 10%. The addition of Ce and La has provided unconventional and unexpected results in UTS and elongation percent of the cast steel component.

[0042] As shown, the system **10** further comprises at least one controller **20** in communication with the molding unit **12**, the furnace **14**, the pouring mechanism **16**, and the separation unit **18**. The controller **20** is configured to control the molding unit **12**, the furnace **14**, the pouring mechanism **16**, and the separation unit **18**. Furthermore, the system **10** comprises a power source **22** configured to power the molding unit **12**, the furnace **14**, the pouring mechanism **16**, the separation unit **18**, and the controller **20**.

[0043] In accordance with one example of the present disclosure, FIG. **2** depicts a method **30** of casting a steel alloy having reduced ferrite and enhanced strengths for a component of an engine. The method **30** of FIG. **2** may be performed with the system **10** of FIG. **1**. As shown, the method **30** comprises providing **32** a mold of the component. The step of providing **32** may include making a mold of the component having at least one molded cavity, preferably a plurality of molded cavities, to define the component to be cast. In this example, the mold has a pattern with dimensions identical to the component to be cast. As in the system **10** described above, the mold has patterns made with green or chemically bonded sand. An assembly of core may then be disposed within the mold to further define the dimensions and structure of the pattern. It is to be understood that the mold may be made by any other suitable manner without departing from the spirit or scope of the present disclosure.

[0044] The method **30** further comprises melting **34** a steel solution, such as scrap steel, at between 1620 degrees Celsius (° C.) and 1700° C., preferably 1650° C. In one example, the steel solution may be melted by the furnace **14** discussed above. The furnace **14** may be an electric arc furnace, an induction furnace, or any other suitable furnace without departing from the spirit or scope of the present disclosure. In this example, the steel solution comprises at least one of carbon (C), silicon (Si), manganese (Mn), phosphorus (P), sulfur (S), chromium (Cr), nickel (Ni), molybdenum (Mo), copper (Cu), titanium (Ti), vanadium (V), aluminum (Al), and nitrogen (N), defining a raw charge.

[0045] In this aspect, the method **30** further comprises adding **36** a master alloy solute to the raw charge at between 1620° C. and 1700° C. to define a steel melt.

[0046] Thus, the steel solution may be alloyed in the furnace **14** by adding the master alloy solutes. In a preferred embodiment, the steel melt solution comprises greater than 0.29 weight percent (wt %) C, greater than 0.40 wt % Si, greater than 0.6 wt % Mn, up to 0.03 wt % P, greater than 0.04 wt % S, greater than 0.8 wt % Cr, about 0.2 wt % Ni, greater than 0.15 wt % Mo, greater than 0.25 wt % Cu, up to 0.03 wt % Ti, greater than 0.07 wt % V, greater than 0.02 wt % Al, up to 0.03 wt % N, and 0.01 to 0.06 wt % of at least one of cerium (Ce) and lanthanum (La). As will be described in greater detail below, the addition of 0.01 to 0.06 wt % of the at least one of Ce and La provides unexpected results of reduced ferrite and enhanced strengths to the component to be cast.

[0047] In a preferred example, the steel melt, and hence the component, has a composition of 0.29 to 0.65 weight percent (wt %) carbon, 0.40 to 0.80 wt % silicon, 0.6 to 1.5 wt % manganese, up to 0.03 wt % phosphorus, 0.04 to 0.07 wt % sulfur, 0.8 to 1.4 wt % chromium, 0.2 to 0.6 wt % nickel, 0.15 to 0.55 wt % molybdenum, 0.25 to 2.0 wt % copper, up to 0.03 wt % titanium, 0.07 to 0.17 wt % vanadium, 0.02 to 0.06 wt % aluminum, up to 0.03 wt % nitrogen (N), and 0.01 to 0.06 wt % of at least one of cerium (Ce) and lanthanum. In a more preferred example, the steel melt has a target composition of 0.35 wt % C, 0.45 wt % Si, 1.0 wt % Mn, up to 0.03 wt % P, 0.06 wt % S, 1.0 wt % Cr, 0.2 wt % Ni, 0.25 wt % Mo, 0.45 wt % Cu, up to 0.03 wt % Ti, 0.1 wt % V, 0.03 wt % Al, 0.03 wt % N, and 0.02 wt % of at least one of Ce and La.

[0048] In this example, the steel melt comprises 0.02 wt % of La and Ce. In one example, the steel melt has a La—Ce weight ratio of at least 2:1. In another example, the steel melt has a Ce—La weight ratio of at least 2:1.

[0049] As shown in FIG. **2**, the method **30** further comprises pouring **38** the steel melt in the plurality of molded cavities at about 1600° C., defining the dimensions of the component to be cast. In one example, step of pouring **38** may implement the pouring mechanism **16** and the pouring ladle of the system **10** in FIG. **1**. In this example, the pouring ladle receives the master alloy solutes which are then added to the steel solution, defining the steel melt. The mold may then be gated or sealed with chemically bonded sand.

[0050] As depicted in FIG. **2**, the method **30** further comprises solidifying **40** the target steel alloy in the plurality of molded cavities of the mold at about 450° C., after the master alloy solute is added to the steel solution. The step of solidifying **40** may involve allowing the steel melt to cool to about 450° C. Cooling may be performed in a designated cooling area **17** within the mold to solidify the steel melt (in the plurality of molded cavities of the mold) to form a target steel alloy. The steel alloy has a composition of 0.29 to 0.65 weight percent (wt %) carbon, 0.40 to 0.80 wt % silicon, 0.6 to 1.5 wt % manganese, up to 0.03 wt % phosphorus, 0.04 to 0.07 wt % sulfur, 0.8 to 1.4 wt % chromium, 0.2 to 0.6 wt % nickel, 0.15 to 0.55 wt % molybdenum, 0.25 to 2.0 wt % copper, up to 0.03 wt % titanium, 0.07 to 0.17 wt % vanadium, 0.02 to 0.06 wt % aluminum, up to 0.03 wt % nitrogen (N), and 0.01 to 0.06 wt % of at least one of cerium (Ce) and lanthanum.

[0051] Preferably, the target steel alloy has a target composition of 0.35 wt % C, 0.45 wt % Si, 1.0 wt % Mn, up to 0.03 wt % P, 0.06 wt % S, 1.0 wt % Cr, 0.2 wt % Ni, 0.25 wt % Mo, 0.45 wt % Cu, up to 0.03 wt % Ti, 0.1 wt % V, 0.03 wt % Al, 0.03 wt % N, and 0.02 wt % of at least one of Ce and La.

[0052] The method **30** further comprises separating **42** the target steel alloy from the plurality of molded cavities, defining a cast steel component having reduced ferrite and enhanced strengths. In one example, the step of separating **42** comprises shaking out or removing the mold comprising the chemically bonded sand from the cast steel component. As in the system **10** of FIG. **1**, to accomplish removal of the mold from the cast steel component, an automated unit is used to break the mold and obtain the cast steel component therefrom. For example, a vibration unit or table may be used having a bottom catch screen for receiving mold particles from the mold. It is to be understood that breaking the mold may be achieved by any suitable manner such as a vibrating unit without departing from the spirit or scope of the present disclosure.

[0053] In this example, the step of separating **42** may comprise degating the target steel alloy after removing the mold from the cast steel component and cleaning the target steel alloy after degating. As in the system **10** of FIG. **1**, a shot blast machine may be used to apply or shoot steel beads on surfaces of the target steel alloy. To meet alloy design expectations, the separation unit **18** may also include an inspection area wherein the target steel alloy casting is inspected for its dimensions, mechanical properties, chemical composition, and microstructure. For example, a computerized system such as a CMM may be used to measure mechanical dimensions of the target steel alloy, defining the cast steel component. Any suitable methods and apparatus may be implemented to evaluate mechanical dimensions, mechanical properties, chemical composition, and microstructure of the steel alloy without departing from the spirit or scope of the present disclosure.

[0054] As a result, the cast steel component has an ultimate tensile strength (UTS) of between about 840 MPa and about 1100 MPa. Such range is an unexpected and unconventional result. In this embodiment, the cast steel component has an unexpected elongation percent of between about 7% and about 10%. The addition of Ce and La has provided unexpected results in UTS and elongation percent of the cast steel component.

[0055] FIG. **3**A depicts a first cast steel component **50** without cerium or lanthanum and FIG. **3**B shows a second cast steel component **52** with cerium. The cast steel component **52** of FIG. **3**B is of the same alloy as the cast steel component **50** of FIG. **3**A, but the cast steel component **52** has 0.01 wt % Ce. As it may be desirable to refine ferrite grain size and reduce porosity of the cast steel component, as shown, the cast steel component **52** of FIG. **3**B comprises an unexpected amount or volume of ferrite grains **54** (light shade) that is noticeably less than the ferrite grains **56** (light shade) comprised in the cast steel component **50** of FIG. **3**A.

As shown, the cast steel component **52** of FIG. **3**B comprises ferrite **54** that is less in fraction and smaller in size than the ferrite **56** of the cast steel component **50** of FIG. **3**A. As such, the cast steel component **52** of FIG. **3**B comprises more pearlite lamellae **58** (dark shade) than pearlite lamellae **60** (dark shade) of the cast steel component of FIG. **3**A. As known, ferrite is characteristically softer or weaker than pearlite. Hence, ferrite is less desirable for the intended purpose of the cast steel component of the present disclosure. Results of the data in FIG. **3**B are unexpected.

[0056] It is to be understood that the cast steel component of the present disclosure may be a crankshaft or any other suitable component for a vehicle without departing from the spirit or scope of the present disclosure.

[0057] FIG. **4** depicts a UTS versus alloy graph. As shown, the UTS versus alloy graph indicates that the second cast steel component **52** comprising 0.01 wt % Ce (FIG. **3**B) has an unexpected UTS of about 840 MPa and about 880 MPa. Moreover, the UTS of the second cast steel component **52** of FIG. **3**B is noticeably higher than the UTS of the first cast steel component **50** without Ce or La (FIG. **3**A) which is about 740 MPa to about 780 MPa. Results of the data in FIG. **4** are unexpected.

[0058] FIG. **5** shows a total elongation versus alloy graph, indicating that the cast steel component **52** having 0.01 wt % Ce (FIG. **3**B) has an unexpected elongation percent of between about 7% and about 8%. As shown, the elongation percent of the cast steel component **52** with Ce of FIG. **3**B is lower than the elongation percent of the cast steel component **50** without Ce of FIG. **3**A.

[0059] In another embodiment of the present disclosure, a cast steel alloy for a vehicle is provided. The cast steel alloy has reduced ferrite and enhanced ultimate tensile strength. The cast steel alloy comprises 0.29 to 0.65 weight percent (wt %) carbon (C), 0.40 to 0.80 wt % silicon (Si), 0.6 to 1.5 wt % manganese (Mn), up to 0.03 wt % phosphorus (P), 0.04 to 0.07 wt % sulfur (S), 0.8 to 1.4 wt % chromium (Cr), 0.2 to 0.6 wt % nickel (Ni), 0.15 to 0.55 wt % molybdenum (Mo), 0.25 to 2.0 wt % copper (Cu), up to 0.03 wt % titanium (Ti), 0.07 to 0.17 wt % vanadium (V), 0.02 to 0.06 wt % aluminum (Al), up to 0.03 wt % nitrogen (N), and 0.01 to 0.06 wt % of at least one of cerium (Ce) and lanthanum (La).

[0060] In a preferred embodiment, the cast steel alloy comprises:0.35 wt % C, 0.45 wt % Si, 1.0 wt % Mn, up to 0.03 wt % P, 0.06 wt % S, 1.0 wt % Cr, 0.2 wt % Ni, 0.25 wt % Mo, 0.45 wt % Cu, up to 0.03 wt % Ti, 0.1 wt % V, 0.03 wt % Al, 0.03 wt % N, and 0.02 wt % of at least one of Ce and La. In another embodiment, the cast steel alloy has a Le-Ce weight ratio of greater than 2:1. In yet another embodiment, the cast steel alloy has a Ce—La weight ratio of greater than 2:1. In still another embodiment, the cast steel alloy has an ultimate tensile strength of about 840 MPa and about 880 MPa. Moreover, the cast-steel alloy has an elongation percent of between about 7% and about 8%. Furthermore, the cast steel alloy may be formed of a vehicle component such as a crankshaft.

[0061] The description of the present disclosure is merely exemplary in nature and variations that do not depart from the gist of the present disclosure are intended to be within the scope of the present disclosure. Such variations are not to be regarded as a departure from the spirit and scope of the present disclosure.

1. A method of casting a steel alloy having reduced ferrite and enhanced ultimate tensile strength for a component of an engine, the method comprising:
- providing a mold of the component, the mold having at least one molded cavity;
- melting a steel solution at between 1620 degrees Celsius (° C.) and 1700° C., the steel solution comprising at least one of carbon (C), silicon (Si), manganese (Mn), phosphorus (P), sulfur (S), chromium (Cr), nickel (Ni), molybdenum (Mo), copper (Cu), titanium (Ti), vanadium (V), aluminum (Al), and nitrogen (N), defining a raw charge;
- adding a master alloy solute to the raw charge at between 1620° C. and 1700° C. to define the steel melt, the steel melt comprising greater than 0.29 weight percent (wt %) C, greater than 0.40 wt % Si, greater than 0.6 wt % Mn, up to 0.03 wt % P, greater than 0.04 wt % S, greater than 0.8 wt % Cr, about 0.2 wt % Ni, greater than 0.15 wt % Mo, greater than 0.25 wt % Cu, up to 0.03 wt % Ti, greater than 0.07 wt % V, greater than 0.02 wt % Al, up to 0.03 wt % N, and 0.01 to 0.06 wt % of at least one of cerium (Ce) and lanthanum (La),
- wherein the steel melt has a target composition of 0.35 wt % C, 0.45 wt % Si, 1.0 wt % Mn, up to 0.03 wt % P, 0.06 wt % S, 1.0 wt % Cr, 0.2 wt % Ni, 0.25 wt % Mo, 0.45 wt % Cu, up to 0.03 wt % Ti, 0.1 wt % V, 0.03 wt % Al, 0.03 wt % N, and 0.02 wt % of at least one of Ce and La;
- pouring the steel melt in the at least one molded cavity at about 1600° C.;
- solidifying the target steel alloy in the at least one molded cavity at about 450° C.; and
- separating the target steel alloy from the at least one molded cavity defining a cast steel component having reduced ferrite and enhanced strengths.

2. The method of claim **1** wherein the steel melt comprises 0.02 wt % of La and Ce, the steel melt having a La—Ce weight ratio of greater than 2:1.

3. The method of claim **1** wherein the steel melt comprises 0.02 wt % of Ce and La, the steel melt having a Ce—La weight ratio of greater than 2:1.

4. The method of claim **1** wherein the cast steel component has an ultimate tensile strength of about 840 MPa and about 1100 MPa.

5. The method of claim **1** wherein the cast steel component has an elongation percent of between about 7% and about 10%.

6. The method of claim **1** wherein the step of separating comprises:
- shaking out the at least one molded cavity from target steel alloy;
- degating the target steel alloy after the step of shaking out;
- cleaning the target steel alloy after the step of degating; and
- inspecting the target steel alloy after the step of cleaning to define the cast steel component.

7. The method of claim **1** wherein the step of providing comprises:
- making the mold of the component, the mold having a pattern with dimensions identical to the cast steel component.

8. A system for casting a steel alloy having reduced ferrite and enhanced strengths for a component of an engine, the system comprising:

a molding unit arranged to form a mold of the component, the mold having at least one molded cavity;

a furnace for melting a steel solution and a master alloy solute at between 1620 degrees Celsius (° C.) and 1700° C. to define a steel melt, the steel solution comprising at least one of carbon (C), silicon (Si), manganese (Mn), phosphorus (P), sulfur (S), chromium (Cr), nickel (Ni), molybdenum (Mo), copper (Cu), titanium (Ti), vanadium (V), aluminum (Al), and nitrogen (N),

wherein the steel solution comprises greater than 0.29 weight percent (wt %) C, greater than 0.40 wt % Si, greater than 0.6 wt % Mn, up to 0.03 wt % P, greater than 0.04 wt % S, greater than 0.8 wt % Cr, about 0.2 wt % Ni, greater than 0.15 wt % Mo, greater than 0.25 wt % Cu, up to 0.03 wt % Ti, greater than 0.07 wt % V, greater than 0.02 wt % Al, up to 0.03 wt % N, and 0.01 to 0.06 wt % of at least one of cerium (Ce) and lanthanum (La),

wherein the steel melt has a composition of 0.29 to 0.65 weight percent (wt %) carbon, 0.40 to 0.80 wt % silicon, 0.6 to 1.5 wt % manganese, up to 0.03 wt % phosphorus, 0.04 to 0.07 wt % sulfur, 0.8 to 1.4 wt % chromium, 0.2 to 0.6 wt % nickel, 0.15 to 0.55 wt % molybdenum, 0.25 to 2.0 wt % copper, up to 0.03 wt % titanium, 0.07 to 0.17 wt % vanadium, 0.02 to 0.06 wt % aluminum, up to 0.03 wt % nitrogen (N), and 0.01 to 0.06 wt % of at least one of cerium (Ce) and lanthanum;

a pouring mechanism for pouring the steel melt in the at least one molded cavity at about 1600° C.;

a cooling area for solidifying the target steel alloy in the at least one molded cavity at about 450° C.;

a separation unit for separating the target steel alloy from the at least one molded cavity defining a cast steel component having reduced ferrite and enhanced strengths;

a controller in communication with the molding unit, the furnace, the pouring mechanism, and the shakeout unit, the controller configured to control the molding unit, the furnace, the pouring mechanism, and the separation unit; and

a power source configured to power the molding unit, the furnace, the pouring mechanism, the separation unit, and the controller.

9. The system of claim **8** wherein the steel melt comprises 0.02 wt % of La and Ce, the steel melt having a La—Ce weight ratio of greater than 2:1.

10. The system of claim **8** wherein the steel melt comprises 0.02 wt % of Ce and La, the steel melt having a Ce—La weight ratio of greater than 2:1.

11. The system of claim **8** wherein the cast steel component has an ultimate tensile strength of about 840 MPa and about 1100 MPa.

12. The system of claim **8** wherein the cast steel component has an elongation percent of between about 7% and about 10%.

13. The system of claim **8** wherein the separation unit is arranged to shakeout the at least one molded cavity from target steel alloy, degate the target steel alloy after shaking out the at least one molded cavity, clean the target steel alloy after degating the target steel alloy; and inspect the target steel alloy after the cleaning the target steel alloy, defining the cast steel component.

14. The system of claim **8** wherein the steel melt has a target composition of 0.35 wt % C, 0.45 wt % Si, 1.0 wt % Mn, up to 0.03 wt % P, 0.06 wt % S, 1.0 wt % Cr, 0.2 wt % Ni, 0.25 wt % Mo, 0.45 wt % Cu, up to 0.03 wt % Ti, 0.1 wt % V, 0.03 wt % Al, 0.03 wt % N, and 0.02 wt % of at least one of Ce and La;

15. A cast steel alloy comprising:

0.29 to 0.65 weight percent (wt %) carbon (C);

0.40 to 0.80 wt % silicon (Si);

0.6 to 1.5 wt % manganese (Mn);

up to 0.03 wt % phosphorus (P);

0.04 to 0.07 wt % sulfur (S);

0.8 to 1.4 wt % chromium (Cr);

0.2 to 0.6 wt % nickel (Ni);

0.15 to 0.55 wt % molybdenum (Mo);

0.25 to 2.0 wt % copper (Cu);

up to 0.03 wt % titanium (Ti);

0.07 to 0.17 wt % vanadium (V);

0.02 to 0.06 wt % aluminum (Al);

up to 0.03 wt % nitrogen (N); and

0.01 to 0.06 wt % of at least one of cerium (Ce) and lanthanum (La).

16. The cast steel alloy of claim **15** wherein the cast steel component comprises:0.35 wt % C, 0.45 wt % Si, 1.0 wt % Mn, up to 0.03 wt % P, 0.06 wt % S, 1.0 wt % Cr, 0.2 wt % Ni, 0.25 wt % Mo, 0.45 wt % Cu, up to 0.03 wt % Ti, 0.1 wt % V, 0.03 wt % Al, 0.03 wt % N, and 0.02 wt % of at least one of Ce and La;

17. The cast steel alloy of claim **15** wherein the steel alloy has a La—Ce weight ratio of greater than 2:1.

18. The cast steel alloy of claim **15** wherein steel alloy has a Ce—La weight ratio of greater than 2:1.

19. The cast steel alloy of claim **15** wherein the steel alloy has an ultimate tensile strength of about 840 MPa and about 1100 MPa.

20. The cast steel alloy of claim **15** wherein the cast steel alloy is formed of a cast steel component.

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