DESCRIPTION

TITLE OF INVENTION:

HOT WORK TOOL STEEL POWDER FOR ADDITIVE MANUFACTURING AND ADDITIVELY MANUFACTURED HOT WORK TOOL STEEL OBJECT

Technical Field

[0001] The present invention relates to hot work tool steel powder for additive manufacturing and an additively manufactured hot work tool steel object.

Background Art

[0002] Hot work tool steel, such as hot forging molds and die casting molds, requires characteristics of high-temperature strength, toughness, and wear resistance for contact with high-temperature workpieces. Conventionally, to satisfy these requirements, JIS steel grade SKD61 or improved steel of SKD61 has been applied to hot work tool steel.

[0003] Recently, additive manufacturing methods have been attracting attention as means to easily form metal products (parts) with complex shapes in near-net shapes. Generally, an additive manufacturing method is also called 3D printing, which is an additive manufacturing technique. As the types of additive manufacturing methods, there are, for example, a powder spray method in which metal powder is irradiated with a heat source and melted while layering, and a powder bed method in which metal powder filled on a stage is irradiated with a heat source and melted, and the work of solidifying this is repeated to build up layers. According to the additive manufacturing method, metal products with complex shapes can be manufactured with significant reduction of conventional machining processes, which makes it possible to use a metal material with low workability. Since a metal material with low workability is also primarily a high-strength metal material, it can manufacture metal products with complex shapes and long durability.

[0004] Further, an additively manufactured object manufactured by the above-mentioned additive manufacturing method using hot work tool steel as the metal material has been proposed. For example, Patent Literature 1 proposes an additively manufactured hot work tool that is characterized by having a component composition including, by mass%, C: 0.3% to 0.5%, Si: 2.0% or less, Mn: 1.5% or less, P: 0.05% or less, S: 0.05% or less, Cr: 3.0% to 6.0%, one or two of Mo and W according to the relationship formula (Mo + 1/2W): 0.5% to 3.5%, V: 0.1% to 1.5%, Ni: 0% to 1.0%, Co: 0% to 1.0%, and Nb: 0% to 0.3%, with the remainder being Fe and unavoidable impurities, in which the area ratio of defects having an area of 1 μm^2 or more in a cross-section parallel to the layering direction is 0.6% or less.

[0005] Patent Literature 2 discloses steel powder that aims to achieve both high thermal conductivity and high corrosion resistance, characterized by having a composition of, by mass%, $0.10 \leqq C < 0.25$, $0.005 \leqq Si \leqq 0.600$, $2.00 \leqq Cr \leqq 6.00$, $-0.0125 \times [Cr] + 0.125 \leqq Mn \leqq -0.100 \times [Cr] + 1.800$ ... formula (a) (where [Cr] in formula (a) represents the content mass% of Cr), $0.01 \leqq Mo \leqq 1.80$, $-0.00447 \times [Mo] + 0.010 \leqq V \leqq -0.1117 \times [Mo] + 0.901$ ... formula (b) (where [Mo] in formula (b) represents the content mass% of Mo), and $0.0002 \leqq N \leqq 0.3000$, with the remainder being Fe and unavoidable impurities.

Related Art Literatures

Patent Literatures

[0006]

Patent Literature 1: International Publication No. 2019/220917

Patent Literature 2: Japanese Patent Application Laid-Open No. 2016-145407

SUMMARY OF INVENTION

Problems to be Solved by the Invention

[0007] As described above, several steels for additive manufacturing have been proposed, but

cracks may occur during additive manufacturing depending on the types of additive manufacturing machines, additive manufacturing conditions, additive manufacturing dimensions, etc. For example, in large-scale additive manufacturing molds or additive manufacturing molds formed with complex cavities, the additive manufacturing molds that have stress concentration portions (recessed portions) and in which stress is particularly concentrated at such portions tend to be highly susceptible to cracking. Thus, further improvement in crack resistance is required.

Therefore, an objective of the present invention is to provide hot work tool steel powder for additive manufacturing that can obtain an additively manufactured hot work tool steel object capable of particularly improving crack resistance during additive manufacturing.

Means for Solving the Problems

[0008] The present invention has been made in view of the above-mentioned problems.

That is, one aspect of the present invention is hot work tool steel powder for additive manufacturing, including, by mass%, $0.10\% \leqq C \leqq 0.40\%$, $0.01\% \leqq Si \leqq 0.19\%$, $0.1\% \leqq Mn \leqq 1.0\%$, $2.0\% \leqq Ni \leqq 9.0\%$, $3.5\% < Cr < 4.5\%$, one or two of Mo and W according to a relationship formula (Mo + 1/2W): $2.5\% \leqq (Mo + 1/2W) < 3.5\%$, $0.45\% \leqq V \leqq 1.0\%$, $0.3\% < Cu < 0.6\%$, $0.2\% \leqq Al \leqq 0.9\%$, with a remainder being Fe and unavoidable impurities, and satisfying formula (1): $C + Si/30 + (Mn + Cr + Cu)/20 + Ni/60 + (Mo + 1/2W)/15 + V/10 \leqq 0.95$ (each element symbol in formula (1) represents a content (mass%) of the element).

[0009] In addition, another aspect of the present invention is an additively manufactured hot work tool steel object, including, by mass%, $0.10\% \leqq C \leqq 0.40\%$, $0.01\% \leqq Si \leqq 0.19\%$, $0.1\% \leqq Mn \leqq 1.0\%$, $2.0\% \leqq Ni \leqq 9.0\%$, $3.5\% < Cr < 4.5\%$, one or two of Mo and W according to a relationship formula (Mo + 1/2W): $2.5\% \leqq (Mo + 1/2W) < 3.5\%$, $0.45\% \leqq V \leqq 1.0\%$, $0.3\% < Cu < 0.6\%$, $0.2\% \leqq Al \leqq 0.9\%$, with a remainder being Fe and unavoidable impurities, and satisfying formula (1): $C + Si/30 + (Mn + Cr + Cu)/20 + Ni/60 + (Mo + 1/2W)/15 + V/10 \leqq 0.95$.

Effects of the Invention

[0010] According to the present invention, hot work tool steel powder for additive manufacturing can be obtained that is capable of manufacturing an additively manufactured hot work tool steel object having particularly excellent crack resistance during additive manufacturing.

BRIEF DESCRIPTION OF DRAWINGS

[0011]

[FIG. 1] is a schematic diagram of a crack evaluation test specimen for evaluating manufacturing crack susceptibility.

[FIG. 2] is a graph of the tempering temperature and hardness of additively manufactured hot work tool steel objects of the example of the present invention and the comparative example.

[FIG. 3] is a graph showing the mechanical properties at room temperature of the example of the present invention ((a) 0.2% proof stress, (b) tensile strength, (c) elongation, (d) reduction of area).

[FIG. 4] is a graph showing the mechanical properties at high temperature of the example of the present invention ((a) 0.2% proof stress, (b) tensile strength, (c) elongation, (d) reduction of area).

[FIG. 5] is a graph showing the Charpy impact value at room temperature of the example of the present invention.

[FIG. 6] is a graph showing the thermal conductivity of the example of the present invention.

DESCRIPTION OF EMBODIMENTS

[0012] The present invention has a component composition including $0.10\% \leqq C \leqq 0.40\%$, $0.01\% \leqq Si \leqq 0.19\%$, $0.1\% \leqq Mn \leqq 1.0\%$, $2.0\% \leqq Ni \leqq 9.0\%$, $3.5\% < Cr < 4.5\%$, one or two of Mo and W according to a relationship formula $(Mo + 1/2W)$: $2.5\% \leqq (Mo + 1/2W) < 3.5\%$, $0.45\% \leqq V \leqq 1.0\%$, $0.3\% < Cu < 0.6\%$, $0.2\% \leqq Al \leqq 0.9\%$, with a remainder being Fe and unavoidable impurities. First, the reasons for limiting the composition of the hot work tool steel powder for additive manufacturing specified in the present invention (hereinafter also referred to as powder

for additive manufacturing or metal powder) will be described. Unless otherwise specified, "%" represents "mass%". In addition, additive manufacturing may be simply referred to as "manufacturing".

C: 0.10% ≦ C ≦ 0.40%

C is a basic element of a hot work tool that partially dissolves in a matrix to provide strength, and partially forms carbide to enhance wear resistance and seizure resistance. Additionally, in a case where C dissolved as an interstitial atom is added together with substitutional atoms having high affinity with C such as Cr, C is an element expected to contribute to the I (interstitial atom)-S (substitutional atom) effect (acting as drag resistance of solute atoms, functioning to strengthen the hot work tool), and is also an element capable of enhancing hardenability. If C is too low, primarily ferrite phase forms during solidification, and the main phase becomes ferrite phase at room temperature, making quenching, which requires rapid cooling from austenite phase, impossible. If the main phase from immediately after solidification to room temperature is ferrite phase, it becomes impossible to mitigate thermal shrinkage by utilizing martensite transformation expansion, thus making cracking more likely to occur. However, as C increases, toughness decreases while hardness improves, which promotes susceptibility to cracking during manufacturing. In the present invention, with the aim to improve crack resistance while maintaining hardness sufficient for mold use, C is set to 0.10% ≦ C < 0.40%. The preferred lower limit of C is 0.15% or more, more preferably 0.18% or more, even more preferably 0.20% or more, and 0.21% or more. In addition, the preferred upper limit of C is 0.35% or less, more preferably 0.30% or less, even more preferably 0.27% or less, 0.25% or less, and 0.24% or less.

[0013] Si: 0.01% ≦ Si ≦ 0.19%

Si can be used as a deoxidizing agent when adjusting the component composition of molten steel, and since it is difficult to manufacture without adding Si and attempting to approach a no-addition level causes an increase in manufacturing costs, the lower limit of Si is set to 0.01% or

more. The preferred lower limit is 0.05% or more, and more preferably 0.08% or more. On the other hand, too much Si leads to the formation of ferrite in the tool structure after tempering. Therefore, the upper limit is set to 0.19% or less. The preferred upper limit is 0.17% or less, more preferably 0.15% or less, and 0.13% or less.

[0014] Mn: 0.1% ≦ Mn ≦ 1.0%

Mn has the effects of enhancing hardenability, suppressing the formation of ferrite in the tool structure, and obtaining appropriate quenching and tempering hardness. To obtain these effects, the lower limit of Mn is set to 0.1% or more. The preferred lower limit is 0.25%, and more preferably 0.40% or more.

On the other hand, if excessive, Mn increases the toughness of the matrix and reduces the machinability of the material. Therefore, the upper limit is set to 1.0% or less. The preferred upper limit is 0.7% or less, more preferably 0.6% or less, and even more preferably 0.55% or less.

[0015] Ni: 2.0% ≦ Ni ≦ 9.0%

Ni is an element that suppresses the formation of ferrite in the tool structure. In addition, together with C, Cr, Mn, Mo, W, etc., Ni is an effective element for imparting excellent hardenability to the tool material, and forming a martensite-based structure even in a case where the cooling rate during quenching is moderate to prevent a decrease in toughness. Furthermore, the Ms point can be reduced. In the case of an additive manufacturing apparatus without a temperature control mechanism, the temperature during manufacturing may approach room temperature depending on the manufacturing conditions. However, in the case where the Ms point is reduced to approach room temperature, the effect of mitigating thermal shrinkage by martensite transformation expansion can be utilized to reduce deformation caused by thermal shrinkage. Therefore, in the present invention, the lower limit of Ni is set to 2.0%. The preferred lower limit is 4.0%, more preferably 5.0% or more, even more preferably 6.0% or more, 7.0% or more, and 7.5% or more. However, excessive Ni is an element that increases the

toughness of the matrix and decreases machinability, and also causes an increase in raw material costs. Therefore, the upper limit of Ni is set to 9.0% even in the case where Ni is contained. The preferred upper limit is 8.5%. In the case where a significant improvement in crack resistance is desired, the particularly preferred range of Ni is 7.5% to 8.5%. In addition, in the case where a significant improvement in thermal conductivity is desired while also ensuring crack resistance, the particularly preferred range of Ni is 3.5% to 4.5%. Furthermore, in the case where improvement in thermal conductivity and proof stress is desired while also ensuring crack resistance, the particularly preferred range of Ni is 5.5% to 6.5%.

[0016] Cr: 3.5% < Cr < 4.5%

Cr is a basic element of a hot work tool that enhances hardenability, forms carbide, and has the effects of strengthening the matrix and improving wear resistance and toughness. However, too much Cr leads to a decrease in hardenability and high-temperature strength. Therefore, Cr is set to 3.5% < Cr < 4.5%. The preferred lower limit of Cr is 3.6% or more, more preferably 3.7% or more, and 3.8% or more. In addition, the preferred upper limit of Cr is 4.4% or less, more preferably 4.3% or less, and 4.2% or less.

[0017] One or two of Mo and W according to the relationship formula: (Mo + 1/2W): 2.5% ≦ (Mo + 1/2W) < 3.5%

Mo and W can be included individually or in combination to impart strength by precipitating or agglomerating fine carbide through tempering, and to improve softening resistance and high-temperature strength. In the present invention, as C is lowered to improve crack resistance, an effect of complementing strength can be expected by including Mo and W at a slightly higher content. In this case, the content can be specified together in terms of Mo equivalent defined by the relationship formula (Mo + 1/2W), since W has about twice the atomic weight of Mo (of course, either one may be included alone, or both may be included together). To obtain the above effects, the value according to the relationship formula (Mo + 1/2W) is set to 2.5% or more. The

preferred lower limit is 2.7% or more, more preferably 2.9% or more, and 3.0% or more. However, Mo and W, if excessive, may lead to a decrease in machinability and toughness, resulting in reduced crack resistance, and because Mo and W have high melting points which increase the difficulty of melting, a large amount of content is not preferable for manufacturing. Therefore, the value according to the relationship formula (Mo + 1/2W) is set to less than 3.5%. The preferred upper limit is 3.4% or less, more preferably 3.3% or less, and 3.2% or less. Here, since W is a more expensive element than Mo, including Mo alone is preferred in a case where cost reduction is prioritized.

[0018] V: 0.45% ≦ V ≦ 1.0%

V has the effect of forming vanadium carbide, which strengthens the matrix and improves wear resistance and tempering softening resistance. In a case where "quenching" is performed by heating an additively manufactured object formed in the additive manufacturing process to the quenching temperature, the above-mentioned vanadium carbide also acts as a "pinning particle" that suppresses the coarsening of austenite crystal grains during quenching heating, and contributes to improvement of toughness. However, since V has high carbide-forming ability, if there is too much V, all C may become vanadium carbide, making it impossible to form other carbides. Since tool steel is established by the presence of multiple types of carbides, it is not desirable to have only vanadium carbide. Therefore, V is set to 0.45% ≦ V ≦ 1.0%. The preferred lower limit is 0.50%, more preferably 0.52% or more, and 0.55% or more. In addition, the preferred upper limit is 0.80%, more preferably 0.70% or less, 0.67% or less, and 0.65% or less.

[0019] Cu: 0.3% < Cu < 0.6%

Cu is an element that suppresses the formation of ferrite in the tool structure. In addition, together with C, Cr, Mn, Ni, Mo, W, etc., Cu is an effective element for imparting excellent hardenability to the tool material, and forming a martensite-based structure even in a case where

the cooling rate during quenching is moderate to prevent a decrease in toughness. In addition, with the aim of further improving crack resistance, Cu is set to more than 0.3% (0.3% < Cu). Preferably, Cu is 0.35% or more. On the other hand, excessive addition of Cu causes Cu to precipitate as a single substance in Fe and decreases toughness. Accordingly, Cu is set to less than 0.6% (Cu < 0.6%). Preferably, Cu is 0.45% or less, and 0.42% or less.

[0020] Al: 0.2% ≦ Al ≦ 0.9%

Al is an element that forms intermetallic compounds such as Ni_3Al with Ni, and has the effect of precipitation-strengthening the metal structure. In the present invention, Ni is added, so adding Al can improve hardness. Therefore, the lower limit of Al is set to 0.2%. The preferred lower limit is 0.3%, and more preferably 0.4% or more. However, too much Al may increase non-metallic inclusions in the metal structure and reduce toughness. Accordingly, the upper limit of Al is set to 0.9%. The preferred upper limit is 0.8% or less, more preferably 0.7% or less, and even more preferably 0.6% or less.

[0021] Remainder: Fe and unavoidable impurities

The remainder is Fe and unavoidable impurities. Representative examples of unavoidable impurities include elements such as P, S, Ca, Mg, O (oxygen), N (nitrogen), and B (boron), and it is preferable that these elements are as low as possible. However, since there are additional effects such as control of inclusion morphology, other mechanical properties, and improvement of manufacturing efficiency, a small amount may be contained. In this case, the ranges of Ca ≦ 0.01%, Mg ≦ 0.01%, O ≦ 0.05%, N ≦ 0.05%, and B ≦ 0.05% are sufficient and are the preferred regulatory upper limits of the present invention. In addition, P and S can follow the JIS steel grade SKD61, for example, P ≦ 0.030% and S ≦ 0.020%.

[0022] In the present invention, an additively manufactured hot work tool steel object having particularly excellent crack resistance during manufacturing can be obtained through an overall balance within the above-described component ranges.

[0023] Formula (1): $C + Si/30 + (Mn + Cr + Cu)/20 + Ni/60 + (Mo + 1/2W)/15 + V/10 \leqq 0.95$

In addition to the component specification, one of the characteristics of the present invention is to adjust the left side of the above formula (1) to 0.95 or less. The left side of formula (1) is a modified version of Pcm, which is used as a cold cracking susceptibility index for welding, and C, Si, Mn, Cr, Cu, Ni, Mo, W, and V in formula (1) indicate the content (mass%) of each element. The occurrence of cracking is also a problem in welding, similar to additive manufacturing, and since both involve molten solidified structures, it was found that the index can be applied to crack suppression in additive manufacturing, and was applied to the present invention. Here, while HCS, a hot cracking index, is also known as a welding cracking index, from preliminary studies, the manufacturing cracks in this composition system were largely cracked from the surface, and the morphology was different from hot cracks that tend to occur at solidification interfaces, etc. Since the manufacturing cracks in this composition system are observed in portions where tensile stress due to thermal shrinkage is likely to occur, the cracks are occurring at low temperatures, and thus are presumed to be similar to cold cracking in welding, and in the present invention, Pcm, which is a cold cracking index, was applied. By adjusting each main component so that the left side of formula (1) becomes 0.95 or less, powder for additive manufacturing that is capable of further suppressing cracking during manufacturing can be obtained. The more preferred left side of formula (1) is 0.92 or less, and even more preferably 0.90 or less.

[0024] Formula (2): $545 - 330C + 2Al - 14Cr - 13Cu - 23Mn - 5Mo - 4Nb - 13Ni - 7Si + 3Ti + 4V \leqq 400$

In the present invention, in addition to the component specification, adjustment can be made so that the above formula (2) becomes 400 or less. Formula (2) is a relationship formula between the elements disclosed in the literature (K. Ishida, Journal of Alloys and Compounds, Volume 220 Issues 1-2 1995 p126-131) and the Ms point, and since a higher value of formula (2) is expected to result in a higher Ms point, transformation to brittle martensite tends to occur at high

temperature during additive manufacturing, making cracking more likely to occur due to thermal shrinkage when cooling to room temperature. Formula (2) is preferably 380 or less, more preferably 360 or less, even more preferably 340 or less, particularly preferably 320 or less, and most preferably 300 or less. The lower limit of formula (2) is not particularly limited. However, since an excessively low value of formula (2) is expected to result in a lower Ms point, there is a concern that martensite transformation may not be completed with an excessively low value, austenite may remain, and strength may decrease. Therefore, it is preferable to adjust formula (2) to 200 or more, more preferably 220 or more, even more preferably 240 or more, and 260 or more.

[0025] The hot work tool steel powder for additive manufacturing of the present invention can be manufactured by, for example, a gas atomization method, a water atomization method, a disk atomization method, a plasma atomization method, a rotating electrode method, etc. Among these, the gas atomization method is a method in which molten raw materials prepared to have the desired component composition are heated above the melting points thereof by high-frequency induction heating, and after melting, the molten metal flowing out through fine holes is finely crushed by injecting inert gas such as argon gas or nitrogen gas to the molten metal, and the powder is obtained by rapid cooling and solidification. This gas atomization method can use scrap metal or crude metal raw materials as the molten raw materials, and compared to the plasma atomization method or rotating electrode method which require preparation of raw materials with desired component composition and shape in advance, the gas atomization method can manufacture hot work tool steel powder at a lower cost, making it suitable as a method for obtaining the metal powder for additive manufacturing of the present invention.

[0026] The hot work tool steel powder for additive manufacturing of the present invention preferably has a 50% particle size in the cumulative particle size distribution on a volume basis (hereinafter referred to as "D50") of 10 μm to 250 μm. By setting D50 of the metal powder for

additive manufacturing of the present invention to 250 μm or less, melting of the metal powder becomes easier, and the formation of internal defects in the additively manufactured object can be suppressed.

In addition, by setting D50 of the metal powder for additive manufacturing of the present invention to 10 μm or more, the metal powder becomes less susceptible to the influence of moisture and other factors in the atmosphere during handling and additive manufacturing, and good flowability can be secured.

The cumulative particle size distribution in the powder for additive manufacturing of the present invention is expressed as a cumulative volume particle size distribution, and the D50 thereof can be displayed as a measured value by the laser diffraction scattering method specified in JIS Z 8825.

[0027] The hot work tool steel powder for additive manufacturing of the present invention may have the D50 of the powder adjusted by sieve classification using a mesh or air classification, etc., in accordance with the above-mentioned methods. For example, powder for additive manufacturing used in the powder bed method needs to have coarse powder for additive manufacturing that is difficult to melt removed in order to minimize the range of heat influence, while melting the powder with a laser beam as the heat source. In addition, fine powder with high adhesiveness needs to be removed in order to obtain optimal flowability for ensuring the laying of the powder. Therefore, in the case of applying the powder for additive manufacturing of the present invention to the powder bed method, it is preferable to adjust the D50 to a range of 10 μm to 53 μm. The preferred upper limit of D50 is 40 μm, and the preferred lower limit of D50 is 20 μm. In addition, in the case of applying the powder for additive manufacturing of the present invention to the laser metal deposition method, it is preferable to adjust the D50 to a range of 50 μm to 150 μm.

[0028] By additively manufacturing the above-mentioned hot work tool steel powder for

additive manufacturing of the present invention using the manufacturing method described later, an additively manufactured hot work tool steel object (hereinafter also referred to as additively manufactured object) can be obtained that includes, by mass%, 0.10% ≦ C ≦ 0.40%, 0.01% ≦ Si ≦ 0.19%, 0.1% ≦ Mn ≦ 1.0%, 2.0% ≦ Ni ≦ 9.0%, 3.5% < Cr < 4.5%, one or two of Mo and W according to a relationship formula (Mo + 1/2W): 2.5% ≦ (Mo + 1/2W) < 3.5%, 0.45% ≦ V ≦ 1.0%, 0.3% < Cu < 0.6%, 0.2% ≦ Al ≦ 0.9%, with a remainder being Fe and unavoidable impurities, and satisfies formula (1): C + Si/30 + (Mn + Cr + Cu)/20 + Ni/60 + (Mo + 1/2W)/15 + V/10 ≦ 0.95. This additively manufactured object excels in being particularly resistant to manufacturing cracking.

[0029] The additively manufactured hot work tool steel object of the present invention preferably has a room-temperature (approximately 20°C) tensile strength of 500 MPa to 2000 MPa when the quench and temper hardness is adjusted to 45 HRC ± 2. A more preferred lower limit is 1000 MPa, an even more preferred lower limit is 1200 MPa. The room-temperature 0.2% proof stress when the quench and temper hardness is adjusted to 45 HRC ± 2 is preferably 500 MPa to 2000 MPa. A more preferred lower limit is 800 MPa, an even more preferred lower limit is 1000 MPa, and a still more preferred lower limit is 1100 MPa. The room-temperature elongation when the quench and temper hardness is adjusted to 45 HRC ± 2 is preferably 5% or more. A more preferred lower limit is 8%, and an even more preferred lower limit is 10%. The room-temperature reduction of area when the quench and temper hardness is adjusted to 45 HRC ± 2 is preferably 20% or more. A more preferred lower limit is 30%, and an even more preferred lower limit is 40%. The room-temperature 2 mm U-notch Charpy impact value when the quench and temper hardness is adjusted to 45 HRC ± 2 is preferably 20 J/cm^2 or more. A more preferred lower limit is 30 J/cm^2, and an even more preferred lower limit is 40 J/cm^2.

[0030] The additively manufactured hot work tool steel object of the present invention preferably has a high-temperature (approximately 550°C in the present embodiment) tensile

strength of 400 MPa to 1500 MPa when the quench and temper hardness is adjusted to 45 HRC ± 2. A more preferred lower limit is 500 MPa, and an even more preferred lower limit is 600 MPa. The high-temperature 0.2% proof stress when the quench and temper hardness is adjusted to 45 HRC ± 2 is preferably 300 MPa to 1300 MPa. A more preferred lower limit is 400 MPa, and an even more preferred lower limit is 500 MPa. The high-temperature elongation when the quench and temper hardness is adjusted to 45 HRC ± 2 is preferably 5% or more. A more preferred lower limit is 8%, and an even more preferred lower limit is 10%. The high-temperature reduction of area when the quench and temper hardness is adjusted to 45 HRC ± 2 is preferably 10% or more. A more preferred lower limit is 20%, and an even more preferred lower limit is 30%. Furthermore, the additively manufactured hot work tool steel object of the present invention preferably has a room-temperature thermal conductivity of 5 W/(m·K) or more when the quench and temper hardness is adjusted to 45 HRC ± 2. A more preferred lower limit is 10 W/(m·K), and an even more preferred lower limit is 15 W/(m·K).

[0031] The additively manufactured object of the present invention is most preferably applied to a die casting mold, but may also be applicable to other molds such as plastic molds that require internal cooling mechanisms. Additionally, this additively manufactured object may be applicable to the repair of molds using additive manufacturing of the powder spray method.

Next, an example of the manufacturing processes that can obtain the additively manufactured object of the present invention using the hot work tool steel powder for additive manufacturing of the present invention will be described in order. The manufacturing processes described below assumes the powder bed method unless otherwise specified.

[0032] The manufacturing method according to the present invention includes a process of filling the prepared hot work tool steel metal powder for additive manufacturing of the present invention in a layered manner, and a process of sequentially melting the filled metal powder with a scanning heat source having a diameter larger than the D50 of the metal powder, and forming a

solidified layer by solidifying the metal powder. Then, the additively manufactured object of the present invention can be produced by repeating the process of filling the metal powder in a layered manner and the process of forming the solidified layer to form multiple layered solidified layers. For example, a laser or electron beam can be utilized as the scanning heat source. It is preferable to make the diameter of this scanning heat source larger than the D50 of the metal powder so that the collection of metal powder can be melted uniformly.

[0033] In the manufacturing method according to the present invention, when irradiating laser while scanning the above-mentioned metal powder, the laser output can be set to 50 W to 400 W, the scanning speed can be set to 200 mm/second to 2000 mm/second, and the scanning pitch can be set to 0.02 mm to 0.20 mm. Here, if the layering thickness per scan of the laser is too large, it becomes difficult for heat to transfer throughout the filled metal powder during laser irradiation, and the metal powder does not melt sufficiently, which promotes the generation of internal defects. On the other hand, if the layering thickness per scan is too small, the number of layers required to reach the predetermined size of the additively manufactured object increases, which prolongs the time required for the additive manufacturing process. Therefore, it is preferable that the layering thickness per scan is 10 μm to 200 μm. The more preferred lower limit of the layering thickness is 20 μm, and the more preferred upper limit of the layering thickness is 100 μm. Although a preheating process may be implemented before the above-mentioned additive manufacturing process, since the powder of the present invention has particularly improved crack resistance compared to conventional hot work tool steel powder, it is possible to omit the preheating or lower the temperature before additive manufacturing, for example, as long as the additively manufactured object is small and has few stress concentration portions.

[0034] In the manufacturing method according to the present invention, in order to impart the mechanical properties necessary for use as a metal product, it is preferable to apply tempering treatment at a temperature of 500°C to 700°C to the member as additively manufactured (a state

after additive manufacturing without heat treatment). By performing tempering, the product can be finished into an "additively manufactured hot work tool steel object" having a predetermined hardness. During this period, the above-mentioned additively manufactured object can be shaped into a hot work tool through various machining processes such as cutting and drilling. In this case, annealing can be performed on the additively manufactured object formed in the above-mentioned additive manufacturing process to facilitate machining. Annealing can also be expected to bring the effect of refining vanadium carbide in the structure of the additively manufactured hot work tool after tempering. Then, finishing machining may also be performed after tempering. Further, depending on the circumstances, this finishing machining can also be combined, and the above-mentioned machining processes can be performed collectively on the additively manufactured object after tempering to finish the additively manufactured object into an additively manufactured hot work tool product.

It should be noted that quenching can be performed before the above-mentioned tempering. And, regardless of whether annealing is performed or not, or before or after annealing, normalizing can be performed on the additively manufactured object formed in the additive manufacturing process.

[0035] The tempering temperature varies depending on the target hardness, etc., but is generally about 500°C to 700°C. Additionally, in the case of performing quenching before tempering, the quenching temperature is generally about 900°C to 1100°C. For example, in the case of SKD61 which is a representative JIS steel grade of hot work tool steel, the quenching temperature is about 1000°C to 1030°C, and the tempering temperature is about 550°C to 650°C.

Then, it is preferable that the tempering hardness is 50 HRC (Rockwell hardness) or less or 520 HV (Vickers hardness) or less. More preferably, the tempering hardness is 48 HRC or less or 500 HV or less. Moreover, it is preferable that the tempering hardness is 40 HRC or more or 380 HV or more. More preferably, the tempering hardness is 42 HRC or more or 400 HV or

more. It should be noted that in the present invention, hardness can be measured in accordance with the measurement method described in JIS Z 2245 "Rockwell hardness test - Test method" or JIS Z 2244-1 "Vickers hardness test - Part 1: Test method", and Rockwell C scale hardness (HRC) or Vickers hardness (HV) can be used.

EXAMPLES

[0036] (Example 1)

After preparing each crude metal raw material to have the component composition shown in Table 1, the metal raw materials were charged into a high-frequency induction melting furnace and melted, and gas atomized powder was obtained by crushing the molten metal with argon gas. The particle size of the obtained atomized powder was adjusted by sieve classification using a mesh and air classification to obtain powder for additive manufacturing for the examples of the present invention and the comparative example with a D50 of 35 μm. With the obtained powder for additive manufacturing described above, additively manufactured objects were produced under the manufacturing conditions shown in Table 2 using M290 manufactured by EOS. Table 3 shows the component compositions of the additively manufactured objects of Sample No. 5 produced from the powder of Sample No. 1, Sample No. 6 produced from the powder of Sample No. 2, Sample No. 7 produced from the powder of Sample No. 3, and Sample No. 8 produced from the powder of Sample No. 4. In addition, Table 4 shows the value of formula (1): C + Si/30 + (Mn + Cr + Cu)/20 + Ni/60 + (Mo + 1/2W)/15 + V/10 and the value of formula (2): 545 - 330C + 2Al - 14Cr - 13Cu - 23Mn - 5Mo - 4Nb - 13Ni - 7Si + 3Ti + 4V for Sample Nos. 1 to 8.

[0037] [Table 1]

Sample No.	Chemical composition (mass%)										Remarks
	C	Si	Mn	Ni	Cr	Mo	V	Cu	Al	Remainder	
1	0.23	0.10	0.50	7.97	4.09	3.03	0.58	0.41	0.53	Fe and unavoidable impurities	Example of the present invention
2	0.18	0.10	0.65	＜0.01	4.10	2.37	0.61	＜0.01	0.001	Fe and unavoidable impurities	Comparative example

3	0.22	0.10	0.49	4.01	4.09	3.01	0.58	0.40	0.53	Fe and unavoidable impurities	Example of the present invention
4	0.22	0.10	0.49	6.01	4.09	3.01	0.58	0.40	0.53	Fe and unavoidable impurities	Example of the present invention

※Among unavoidable impurities, P ≦ 0.030%, S ≦ 0.020%, Ca ≦ 0.01%, Mg ≦ 0.01%, O ≦ 0.05%, N ≦ 0.05%, B ≦ 0.05%.

[0038] [Table 2]

Condition No.	Laser output [W]	Scanning speed [mm/s]	Layering thickness [μm]	Scanning pitch [mm]
1	300	800	40	0.09

[0039] [Table 3]

Sample No.	Chemical composition (mass%)										Remarks
	C	Si	Mn	Ni	Cr	Mo	V	Cu	Al	Remainder	
5	0.22	0.10	0.44	8.07	4.04	3.10	0.59	0.38	0.48	Fe and unavoidable impurities	Example of the present invention
6	0.16	0.10	0.56	＜0.01	4.06	2.39	0.60	0.01	0.001	Fe and unavoidable impurities	Comparative example
7	0.21	0.10	0.44	4.06	4.07	3.09	0.59	0.38	0.52	Fe and unavoidable impurities	Example of the present invention
8	0.21	0.10	0.44	6.05	4.05	3.08	0.59	0.38	0.52	Fe and unavoidable impurities	Example of the present invention

※Among unavoidable impurities, P ≦ 0.030%, S ≦ 0.020%, Ca ≦ 0.01%, Mg ≦ 0.01%, O ≦ 0.05%, N ≦ 0.05%, B ≦ 0.05%.

[0040] [Table 4]

Sample No.	Value of formula (1)	Value of formula (2)
1	0.875	279
2	0.642	402
3	0.798	334
4	0.831	308
5	0.868	283
6	0.616	411
7	0.791	338
8	0.822	313

[0041] (Example 2)

In order to evaluate the cracking susceptibility of additively manufactured objects, crack evaluation test specimens having the shape as shown in FIG. 1 were additively manufactured. Specifically, the powders for additive manufacturing of Sample Nos. 1 to 4 from Example 1 were additively manufactured under the same manufacturing conditions as in Example 1, to produce Sample No. 9 (Sample No. 5 composition), Sample No. 10 (Sample No. 6 composition), Sample No. 11 (Sample No. 7 composition), and Sample No. 12 (Sample No. 8 composition) having the same compositions as Sample Nos. 5 to 8. The crack evaluation test specimen had a length of 50 mm, a width of 10 mm, and a height of 16 mm, with a stress concentration portion created at an intermediate position with R8, and the stress concentration portion was formed into a comb-tooth shape to make cracking more likely to occur, assuming an additive manufacturing mold in which a complex cavity was formed. For the crack evaluation test specimen, the cracked length of the comb-tooth portion after manufacturing can be measured to evaluate the cracking susceptibility of the material during manufacturing. Table 5 shows the crack lengths of the crack test specimens of Sample Nos. 9, 11, and 12 (examples of the present invention) and Sample No. 10 (comparative example). From Table 5, it was confirmed that the examples of the present invention had remarkably shorter crack lengths than the comparative example, and had particularly superior crack resistance during manufacturing compared to the comparative example. In particular, Sample No. 9 was confirmed to have a crack length of 1.0 mm or less and have the highest crack resistance.

[0042] [Table 5]

Sample No.	Crack length [mm]	Remarks
9	0.6	Example of the present invention
10	19.5	Comparative example
11	4.5	Example of the present invention

12	1.8	Example of the present invention

[0043] (Example 3)

Next, the tempering behaviors of the examples of the present invention and the comparative example were confirmed. Sample Nos. 5 to 8 shown in Example 1 above were subjected to tempering heat treatment in the temperature range shown in FIG. 2, and the Rockwell hardness based on JIS Z 2245 was measured. FIG. 2 shows a graph of each tempering temperature and hardness. From FIG. 2, it was confirmed that Sample Nos. 5, 7, and 8 of the examples of the present invention can be quenched and tempered to a higher hardness than Sample No. 6 of the comparative example.

[0044] Furthermore, the mechanical properties and thermal conductivity of the examples of the present invention were confirmed. Additively manufactured objects produced under the same conditions as Sample Nos. 5, 7, and 8 (all examples of the present invention) of Example 1 were subjected to tempering heat treatment in the temperature range of 500°C to 700°C, and the test specimens were respectively quenched and tempered to 40 ± 2 HRC, 45 ± 2 HRC, and 52 ± 2 HRC, after which tensile test, 2 mm U-notch Charpy impact test, and thermal conductivity measurement by the laser flash method were performed. FIG. 3 shows the results of the room-temperature (22°C) tensile test, FIG. 4 shows the results of the high-temperature (550°C) tensile test, FIG. 5 shows the results of the Charpy impact test, and FIG. 6 shows the thermal conductivity measurement results.

[0045] According to FIG. 3, the additively manufactured object of the example of the present invention had a room-temperature tensile strength of 1100 MPa or more, a room-temperature 0.2% proof stress of 600 MPa or more, a room-temperature elongation of 12% or more, and a room-temperature reduction of area of 50% or more at all quenching and tempering hardness levels. In addition, according to FIG. 4, the additively manufactured object of the example of the present

invention had a high-temperature tensile strength of 700 MPa or more, a high-temperature 0.2% proof stress of 400 MPa or more, a high-temperature elongation of 13% or more, and a high-temperature reduction of area of 35% or more at all quenching and tempering hardness levels of the example of the present invention.

Further, the additively manufactured object of the example of the present invention, at a hardness of 45 ± 2 HRC, had a room-temperature tensile strength of 1200 MPa or more, a room-temperature 0.2% proof stress of 1100 MPa or more, a room-temperature elongation of 13% or more, and a room-temperature reduction of area of 50% or more. In addition, the additively manufactured object of the example of the present invention, at a hardness of 45 ± 2 HRC, had a high-temperature tensile strength of 800 MPa or more, a high-temperature 0.2% proof stress of 500 MPa or more, a high-temperature elongation of 15% or more, and a high-temperature reduction of area of 35% or more.

[0046] From FIG. 5, it was confirmed that the additively manufactured object of the example of the present invention had a Charpy impact value of 50 J/cm^2 or more at all quenching and tempering hardness levels. In addition, from FIG. 6, it was confirmed that the additively manufactured object of the example of the present invention had a room-temperature thermal conductivity of 15 W/(m·K) or more. In particular, it was confirmed that Sample No. 7 had a room-temperature thermal conductivity of 20 W/(m·K) or more, and had the best thermal conductivity properties.

From the above FIG. 3 to FIG. 6, it was confirmed that the additively manufactured object of the present invention has properties equivalent to those of melted hot work tool steel, and is suitable for applications such as hot work tools.