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 having stress concentration portions (recessed portions) tend to be susceptible to cracking during additive manufacturing. In addition, there are cases in which particularly high toughness is required depending on the application. For example, in the case of additively manufacturing molds that have complex shapes due to the increasing design sophistication of products in recent years, high toughness tends to be required in order to prevent large cracks at stress concentration portions.

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 further improving crack resistance during additive manufacturing and also having excellent toughness.

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, by mass%, hot work tool steel powder for additive manufacturing, including, by mass%, $0.10\% \leqq C \leqq 0.40\%$, $0.01\% \leqq Si \leqq 0.19\%$, $0.1\% \leqq Mn \leqq 1.0\%$, $0.3 \leqq Ni < 1.0\%$, $3.5\% < Cr < 4.5\%$, one or two of Mo and W according to a relationship formula (Mo + 1/2W): $2.5\% \leqq (Mo + 1/2W) < 3.5\%$, $0.45\% \leqq V \leqq 1.0\%$, $0.1\% \leqq Cu \leqq 1.0\%$, with a remainder being Fe and unavoidable impurities, and satisfying formula (1): $C + Si/30 + (Mn + Cr + Cu)/20 + Ni/60 + (Mo + 1/2W)/15 + V/10 \leqq 0.80$ (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%, $0.10\% \leqq C \leqq 0.40\%$, $0.01\% \leqq Si \leqq 0.19\%$, $0.1\% \leqq Mn \leqq 1.0\%$, $0.3 \leqq Ni < 1.0\%$, $3.5\% < Cr < 4.5\%$, 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%, 0.1% ≦ Cu ≦ 1.0%, 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 ≦ 0.80.

Effects of the Invention

[0010] According to the present invention, hot work tool steel powder for additive manufacturing is provided that can obtain an additively manufactured hot work tool steel object capable of further improving crack resistance during additive manufacturing and also having excellent toughness.

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 showing 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% ≦ C ≦ 0.40%,

0.01% ≦ Si ≦ 0.19%, 0.1% ≦ Mn ≦ 1.0%, 0.3 ≦ Ni < 1.0%, 3.5% < Cr < 4.5%, 2.5% < (Mo + 1/2W) < 3.5%, 0.45% ≦ V ≦ 1.0%, 0.1% ≦ Cu ≦ 1.0%, 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%, more preferably 0.18% or more, and even more preferably 0.20% or more. In addition, the preferred upper limit of C is 0.35%, 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%. The preferred lower limit is 0.05%, 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%. The preferred upper limit is 0.17%, 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%. 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, and therefore, the upper limit is set to 1.0%, preferably 0.7% or less, more preferably 0.6% or less, and even more preferably 0.55% or less.

[0015] Ni: 0.3% ≦ Ni < 1.0%

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, since Ni also improves the intrinsic toughness of the matrix, the lower limit of Ni is set to 0.3%, preferably 0.5% or more, and more preferably 0.7% or more. However, excessive Ni increases the toughness of the matrix and decreases machinability. Therefore, the upper limit is set to less than 1.0%, preferably 0.90% or less, and even more preferably 0.85% or less.

[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%, more preferably 3.7% or more, and 3.8% or more. In addition, the preferred upper limit of Cr is 4.4%, 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 one or two of 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 (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 more preferred lower limit is 2.7%, even 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%, preferably 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: 0.1% ≦ Cu ≦ 1.0%

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. On the other hand, excessive addition of Cu causes Cu to precipitate as a single substance in Fe and decreases toughness. Therefore, Cu is set to 0.1% ≦ Cu ≦ 1.0%. The preferred lower limit is 0.2% or more, more preferably 0.30% or more, 0.33% or more, and 0.35% or more. In addition, the preferred upper limit is 0.7% or less, more preferably 0.5% or less, 0.48% or less, 0.45% or less, and 0.42% or less.

[0020] Remainder: Fe and unavoidable impurities

The remainder is Fe and unavoidable impurities. Representative examples of unavoidable

impurities include elements such as P, S, Al, 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, it is acceptable to include a small amount. In this case, the ranges of Al ≦ 0.04%, 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. For Al, more preferably, Al is 0.025% or less. Also, P and S can follow the JIS steel grade SKD61, for example, P ≦ 0.030% and S ≦ 0.020%.

[0021] In the present invention, an additively manufactured hot work tool steel object with particularly excellent toughness can be obtained through an overall balance within the above-described component ranges.

[0022] Formula (1): $C + Si/30 + (Mn + Cr + Cu)/20 + Ni/60 + (Mo + 1/2W)/15 + V/10 \leqq 0.80$

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 0.80 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 0.80 or less, powder that is capable of further suppressing cracking during manufacturing can be obtained. The more preferred left side of formula (1) is 0.78 or less, and even more preferably 0.76 or less.

[0023] Formula (2): 545 - 330C + 2Al - 14Cr - 13Cu - 23Mn - 5Mo - 4Nb - 13Ni - 7Si + 3Ti + 4V ≦ 500

In the present invention, in addition to the component specification, adjustment can be made so that the above formula (2) becomes 500 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 450 or less, more preferably 400 or less, and even more preferably 390 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 the lower limit of formula (2) to 200 or more, more preferably 250 or more, even more preferably 300 or more, and 350 or more.

[0024] 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.

[0025] 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 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 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.

[0026] The hot work tool steel powder for additive manufacturing of the present invention may have the D50 of metal powder adjusted by sieve classification using a mesh or air classification, etc., in accordance with the above-mentioned methods. For example, metal powder for additive manufacturing used in the powder bed method needs to have coarse metal powder that is difficult to melt removed in order to minimize the range of heat influence, while melting the metal powder

with a laser beam as the heat source. In addition, fine metal powder with high adhesiveness needs to be removed in order to obtain optimal flowability for ensuring the laying of the metal 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.

[0027] 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 simply referred to as additively manufactured object) can be obtained that includes, by mass%, $0.10\% \leqq C \leqq 0.40\%$, $0.01\% \leqq Si \leqq 0.19\%$, $0.1\% \leqq Mn \leqq 1.0\%$, $0.3 \leqq Ni < 1.0\%$, $3.5\% < Cr < 4.5\%$, one or two of Mo and W according to a relationship formula $(Mo + 1/2W)$: $2.5\% \leqq (Mo + 1/2W) < 3.5\%$, $0.45\% \leqq V \leqq 1.0\%$, $0.1\% \leqq Cu \leqq 1.0\%$, with a remainder being Fe and unavoidable impurities, and satisfies formula (1): $C + Si/30 + (Mn + Cr + Cu)/20 + Ni/60 + (Mo + 1/2W)/15 + V/10+ \leqq 0.80$. This additively manufactured object excels in being resistant to manufacturing cracking and having good toughness. Here, the toughness in the present invention can be evaluated by the Charpy impact value. The preferred Charpy impact value is 30 J/cm^2 or more, more preferably 50 J/cm^2 or more, even more preferably 100 J/cm^2 or more, and particularly preferably 200 J/cm^2 or more. In addition, the Charpy impact value at room temperature (approximately 20°C) is preferably 150 J/cm^2 or more when the quench and temper hardness is adjusted to 45 ± 2 HRC. The Charpy impact value described above can be measured by 2 mm U-notch Charpy impact tests based on JIS Z 2242.

[0028] The additively manufactured hot work tool steel object of the present invention can be

expected to exhibit excellent mechanical properties in addition to the additive manufacturing crack properties and toughness described above. For example, the additively manufactured hot work tool steel object of the present invention preferably has a room-temperature (approximately 20°C) tensile strength of 1000 MPa to 2000 MPa when the quench and temper hardness is adjusted to 45 ± 2 HRC. A more preferred lower limit is 1200 MPa, an even more preferred lower limit is 1300 MPa, and a still more preferred lower limit is 1400 MPa. The room-temperature 0.2% proof stress when the quench and temper hardness is adjusted to 45 ± 2 HRC is preferably 800 MPa to 2000 MPa. A more preferred lower limit is 800 MPa, and an even more preferred lower limit is 1000 MPa. The room-temperature elongation when the quench and temper hardness is adjusted to 45 ± 2 HRC is preferably 8% or more. A more preferred lower limit is 10%, and an even more preferred lower limit is 12%. The room-temperature reduction of area when the quench and temper hardness is adjusted to 45 ± 2 HRC is preferably 30% or more. A more preferred lower limit is 40%, an even more preferred lower limit is 50%, and a still more preferred lower limit is 60%.

[0029] 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 600 MPa to 1400 MPa when the quench and temper hardness is adjusted to 45 ± 2 HRC. A more preferred lower limit is 800 MPa, and an even more preferred lower limit is 900 MPa. The high-temperature 0.2% proof stress when the quench and temper hardness is adjusted to 45H ± 2 RC is preferably 600 MPa to 1200 MPa. A more preferred lower limit is 700 MPa, and an even more preferred lower limit is 800 MPa. The high-temperature elongation when the quench and temper hardness is adjusted to 45 ± 2 HRC is preferably 10% or more. A more preferred lower limit is 13%, and an even more preferred lower limit is 16%. The high-temperature reduction of area when the quench and temper hardness is adjusted to 45 ± 2 HRC is preferably 30% or more. A more preferred lower limit is 40%, an even more preferred lower

limit is 50%, and a still more preferred lower limit is 60%.

[0030] Furthermore, the additively manufactured hot work tool steel object of the present invention preferably has a room-temperature thermal conductivity of 10 W/(m·K) or more when the quench and temper hardness is adjusted to 45 ± 2 HRC. A more preferred lower limit is 15 W/(m·K), an even more preferred lower limit is 20 W/(m·K), and a particularly preferred lower limit is 25 W/(m·K).

[0031] This additively manufactured object 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 hot work tool steel 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 (hereinafter also referred to as "metal powder") 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 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 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 example of the present invention and the comparative example with a D50 of 35 μm. With the obtained metal 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. 3 produced from the powder of Sample No. 1 and Sample No. 4 produced from the powder of Sample No. 2.

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 4.

[0037] [Table 1]

Sample No.	Chemical composition (mass%)									Remarks
	C	Si	Mn	Ni	Cr	Mo	V	Cu	Remainder	
1	0.22	0.10	0.49	0.79	4.09	3.02	0.59	0.40	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	Fe and unavoidable impurities	Comparative example

※Among unavoidable impurities, P ≦ 0.030%, S ≦ 0.020%, Al ≦ 0.04%, 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	Remainder	
3	0.21	0.09	0.43	0.78	4.12	3.08	0.59	0.38	Fe and unavoidable impurities	Example of the present invention
4	0.16	0.10	0.56	＜0.01	4.06	2.39	0.60	0.01	Fe and unavoidable impurities	Comparative example

※Among unavoidable impurities, P ≦ 0.030%, S ≦ 0.020%, Al ≦ 0.04%, 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	0.749	374
2	0.642	402
3	0.738	379
4	0.616	411

[0041] (Example 2)

In order to evaluate the cracking susceptibility of additively manufactured objects, crack evaluation test specimens as shown in FIG. 1 were additively manufactured. Specifically, the powders for additive manufacturing of Sample Nos. 1 and 2 from Example 1 were additively manufactured under the same manufacturing conditions as in Example 1, to obtain No. 5 (No. 3 composition) of the example of the present invention and No. 6 (No. 4 composition) of the comparative example, which had the same compositions as Sample No. 3 and Sample No. 4. 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 No. 5 (example of the present invention) and Sample No. 6 (comparative example). From Table 5, it was confirmed that the example of the present invention had a shorter crack length than the comparative example, and exhibited crack resistance equal to or greater than that of the comparative example.

[0042] [Table 5]

Sample No.	Crack length [mm]	Remarks
5	15.9	Example of the present invention
6	19.5	Comparative example

[0043] (Example 3)

Next, the tempering behaviors of the example of the present invention and the comparative example were confirmed. The samples of Sample Nos. 3 and 4 obtained by the manufacturing method described 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 No. 3 of the example of the present invention can be quenched and tempered to a higher hardness than No. 4 of the comparative example.

[0044] (Example 4)

Next, the toughness of the additively manufactured object of the present invention was evaluated. Gas atomized powders having the alloy compositions of Sample No. 1 and Sample No. 2 obtained by the manufacturing method described in Example 1 were prepared. Then, using M290 manufactured by EOS, additively manufactured objects of Sample No. 7 of the example of the present invention (same as No. 3 composition) and Sample No. 8 of the comparative example (same as No. 4 composition) were produced under additive manufacturing conditions with laser output: 300 W, scanning speed: 800 mm/s, and layering thickness: 40 μm. Sample No. 7 was

subjected to tempering at 605°C to 610°C and tempered to a hardness of 45 ± 2 HRC. Sample No. 8 was subjected to tempering at 550°C and tempered to the same hardness of 45 ± 2 HRC as Sample No. 4. Hardness was measured using a Rockwell hardness tester in accordance with JIS Z 2245. Subsequently, Charpy impact test specimens were taken from the obtained Sample No. 7 and Sample No. 8 in the horizontal direction relative to the layering direction. Then, 2 mm U-notch Charpy impact tests in accordance with JIS Z 2242 were conducted on the obtained test specimens.

The results of toughness obtained are shown in Table 6. From the results in Table 6, it was confirmed that the example of the present invention, with test specimens quenched and tempered to a hardness of 45 ± 2 HRC, had a Charpy impact value of 200 J/cm^2 or more and exhibited toughness superior to that of the comparative example.

[0045] [Table 6]

Sample No.	Charpy impact value [J/cm^2]	Remarks
7	232.8	Example of the present invention
8	155.7	Comparative example

[0046] Furthermore, the mechanical properties and thermal conductivity of the example of the present invention were confirmed. Test specimens produced under the same conditions as Sample No. 3 (example of the present invention) of Example 1 were subjected to tempering heat treatment in the temperature range of 500°C to 700°C and quenched and tempered to 40 ± 1 HRC, 45 ± 1 HRC, and 49 ± 1 HRC, after which tensile test and 2 mm U-notch Charpy impact test were performed. In addition, after quenching and tempering the test specimens to 45 ± 1 HRC, thermal conductivity measurement by the laser flash method was 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.

[0047] According to FIG. 3, the additively manufactured object of the example of the present invention had a room-temperature tensile strength of 1200 MPa or more, a room-temperature 0.2% proof stress of 1000 MPa or more, a room-temperature elongation of 13% or more, and a room-temperature reduction of area of 60% 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 800 MPa or more, a high-temperature 0.2% proof stress of 600 MPa or more, a high-temperature elongation of 13% or more, and a high-temperature reduction of area of 50% 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 ± 1 HRC, had a room-temperature tensile strength of 1400 MPa or more, a room-temperature 0.2% proof stress of 1200 MPa or more, a room-temperature elongation of 13% or more, and a room-temperature reduction of area of 60% or more. In addition, the additively manufactured object of the example of the present invention, at a hardness of 45 ± 1 HRC, had a high-temperature tensile strength of 900 MPa or more, a high-temperature 0.2% proof stress of 700 MPa or more, a high-temperature elongation of 18% or more, and a high-temperature reduction of area of 60% or more.

[0048] From FIG. 5, it was confirmed that the additively manufactured object of the example of the present invention had a Charpy impact value of 100 J/cm^2 or more at all quenching and tempering hardness levels. In particular, at hardness levels of 40 ± 1 HRC and 45 ± 1 HRC, the Charpy impact value was 150 J/cm^2 or more, which was a favorable value. In addition, from FIG. 6, it was confirmed that the additively manufactured object of the example of the present invention, at a hardness of 45 ± 1 HRC, had a room-temperature thermal conductivity of 25 W/(m·K) or more.

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 conventionally melted hot work tool steel, and is suitable for applications such as hot work tools.

CLAIMS

[Claim 1]

Hot work tool steel powder for additive manufacturing, comprising, by mass%, 0.10% ≦ C ≦ 0.40%, 0.01% ≦ Si ≦ 0.19%, 0.1% ≦ Mn ≦ 1.0%, 0.3 ≦ Ni < 1.0%, 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%, 0.1% ≦ Cu ≦ 1.0%, with a remainder being Fe and unavoidable impurities, and further satisfying the following formula (1),

formula (1): C + Si/30 + (Mn + Cr + Cu)/20 + Ni/60 + (Mo + 1/2W)/15 + V/10 ≦ 0.80,

where each element symbol in formula (1) represents a content (mass%) of the element.

[Claim 2]

An additively manufactured hot work tool steel object, comprising, by mass%, 0.10% ≦ C ≦ 0.40%, 0.01% ≦ Si ≦ 0.19%, 0.1% ≦ Mn ≦ 1.0%, 0.3 ≦ Ni < 1.0%, 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%, 0.1% ≦ Cu ≦ 1.0%, with a remainder being Fe and unavoidable impurities, and further satisfying the following formula (1),

formula (1): C + Si/30 + (Mn + Cr + Cu)/20 + Ni/60 + (Mo + 1/2W)/15 + V/10 ≦ 0.80,

where each element symbol in formula (1) represents a content (mass%) of the element.