(19) Europäisches Patentamt / European Patent Office / Office européen des brevets

(11) **EP 4 123 047 A1**

(12) **EUROPEAN PATENT APPLICATION**
published in accordance with Art. 153(4) EPC

(43) Date of publication:
25.01.2023 Bulletin 2023/04

(21) Application number: **21772321.2**

(22) Date of filing: **16.03.2021**

(51) International Patent Classification (IPC):
C22C 38/00 *(2006.01)* ***C21D 1/06*** *(2006.01)*
C21D 9/00 *(2006.01)* ***C22C 38/58*** *(2006.01)*

(52) Cooperative Patent Classification (CPC):
C21D 1/06; C21D 9/00; C22C 38/00; C22C 38/58

(86) International application number:
PCT/JP2021/010616

(87) International publication number:
WO 2021/187484 (23.09.2021 Gazette 2021/38)

(84) Designated Contracting States:
AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL PT RO RS SE SI SK SM TR
Designated Extension States:
BA ME
Designated Validation States:
KH MA MD TN

(30) Priority: **16.03.2020 JP 2020045361**

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(54) **STEEL FOR HOT WORKING DIE, DIE FOR HOT WORKING, AND MANUFACTURING METHOD FOR SAME**

(57) Provided are: a steel that is for a die and that enables production of a die being for hot working and having both high hardness and high thermal conductivity; a die for hot working; and a manufacturing method for the same. The steel for a hot working die has a compositional makeup containing, in mass%, 0.45-0.65% of C, 0.1-0.6% of Si, 0.1-2.5% of Mn, 1.0-6.0% of Cr, 1.2-3.5% of (Mo+1/2W) where Mo and W are contained independently or in combination, 0.1-0.5% of V, 0.15-0.6% of Ni, 0.1-0.6% of Cu, and 0.1-0.6% of Al, the balance being Fe and inevitable impurities. Further, this die for hot working has said compositional makeup, and this manufacturing method is for manufacturing said die for hot working.

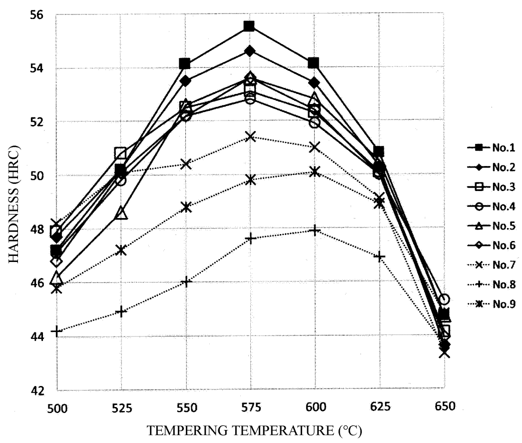

FIG. 1

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Description

[Technical Field]

[0001] The present invention relates to a steel for a hot working die, a die for hot working and a manufacturing method for the same.

[Background Art]

[0002] In recent years, for the purpose of weight reduction and collision safety improvement of cars, a need for an ultrahigh strength steel sheet having a tensile strength of higher than 1 GPa has been intensifying. However, when an attempt is made to form a steel sheet having a tensile strength of 1.2 GPa or higher by hot pressing, an increase in the forming load or spring back and a problem with formability or the like are caused. Therefore, recently, a hot stamping (also referred to as hot pressing or hot stamping) method has been gaining attention. In the hot stamping method, a steel sheet is heated to an austenite temperature or higher and then pressed, a die is held at the bottom dead center, and the steel sheet is rapidly cooled and quenched.

[0003] An advantage of the hot stamping method is that a formed product of an ultrahigh strength steel sheet having a tensile strength of approximately 1.5 GPa can be obtained by quenching through die quenching where the steel sheet is rapidly cooled in a die. In addition, another advantage is that the formability is so excellent that spring back rarely occurs.

[0004] However, the hot stamping method has a problem of poor productivity. That is, time is required to hold the bottom dead center for die quenching or the like, and thus the productivity becomes poor. As a measure for this, a die having high thermal conductivity is in demand. This is because, during die quenching, heat from a steel sheet is absorbed into a die; however, as the thermal conductivity of the die becomes higher, the time taken to hold the die at the bottom dead center becomes shorter, and the productivity becomes more favorable. In addition, dies for hot stamping are required to have high hardness in order to enhance wear resistance, and steels for hot stamping dies are required to have both high hardness and high thermal conductivity when made into dies.

[0005] In the fields of hot forging or die casting as well, there is a tendency that steels for dies having both high thermal conductivity and high hardness as described above are required to achieve the extension of the service lives of dies or additional improvement in production efficiency. Ordinarily, the amount of an alloy in a steel for a die needs to be increased to obtain a die having high hardness, but an increase in the amount of an alloy leads to a problem of a decrease in the thermal conductivity of the die, and hardness and thermal conductivity have a trade-off relationship. Therefore, studies are underway to obtain an optimal compositional makeup by controlling the amount of an alloy. For example, in Patent Literature 1 and Patent Literature 2, a compositional makeup of a steel for a die having both hardness and thermal conductivity has been proposed. In addition, Patent Literature 3 and Patent Literature 4 also disclose hot work tool steels that are useful as a material for dies that are used in warm and hot pressing, die casting, warm and hot forging and the like, have excellent thermal conductivity and also have excellent wear resistance.

[Citation List]

[Patent Literature]

[0006]

[Patent Literature 1]
Japanese Patent Laid-Open No. 2017-43814
[Patent Literature 2]
Japanese Patent Laid-Open No. 2018-24931
[Patent Literature 3]
Japanese Patent No. 5744300
[Patent Literature 4]
Japanese Patent Laid-Open No. 2017-53023

[Summary of Invention]

[Technical Problem]

[0007] The steels for a die of Patent Literature 1 and 2 and the hot work tool steels of Patent Literature 3 and 4 are useful inventions that enable hardness and thermal conductivity to be increased. However, when the quenching and tempering characteristics of steels for dies or hot work tool steels, the fact that the work surface of a die for hot stamping or the like is used after a nitriding treatment and the like are taken into account, there have been cases where conventional steels for a die or hot work tool steels lack hardness. Specifically, in recent years, there has been a demand for a steel for a die capable of achieving a high hardness of 52 HRC or higher as a die for hot stamping or the like, but a high hardness of 52 HRC or higher cannot be stably obtained with Patent Literature 1-3. In addition, since the tempering temperature where the highest hardness of a steel for a die can be obtained is ordinarily near 575°C, if the highest hardness of a steel for a die does not reach 52 HRC, the hardness of a die further decreases from lower than 52 HRC due to the nitriding treatment or an increase in temperature during use.

[0008] An objective of the present invention is to provide a steel for a hot working die having both higher hardness and higher thermal conductivity than ever and enabling the production of a die where the hardness is maintained, a die for hot working and a manufacturing method for the same.

[Solution to Problem]

[0009] In consideration of such circumstances, the present inventor found a compositional makeup that allows the control of the amount of an alloy, is capable of achieving high hardness and high thermal conductivity and is capable of maintaining the achieved high hardness (that is, the softening resistance is large) and reached a steel for hot working die of the present invention. In addition, the present inventor found a die for hot working capable of achieving high hardness and high thermal conductivity and also having excellent softening resistance by the use of the steel for a die and a manufacturing method for the same.

[0010] That is, an aspect of the present invention is a steel for a hot working die having a compositional makeup containing, in mass%, 0.45-0.65% of C, 0.1-0.6% of Si, 0.1-2.5% of Mn, 1.0-6.0% of Cr, 1.2-3.5% of (Mo+1/2W) where Mo and W are contained independently or in combination, 0.1-0.5% of V, 0.15-0.6% of Ni, 0.1-0.6% of Cu, and 0.1-0.6% of Al or less, a balance being Fe and inevitable impurities.

[0011] Preferably, when the steel has been tempered at 575°C, a hardness is 52 HRC or higher.

[0012] Another aspect of the present invention is a die for hot working having a compositional makeup containing, in mass%, 0.45-0.65% of C, 0.1-0.6% of Si, 0.1-2.5% of Mn, 1.0-6.0% of Cr, 1.2-3.5% of (Mo+1/2W) where Mo and W are contained independently or in combination, 0.1-0.5% of V, 0.15-0.6% of Ni, 0.1-0.6% of Cu, and 0.1-0.6% of Al or less, a balance being Fe and inevitable impurities.

[0013] Preferably, a hardness is 52 HRC or higher, and a thermal conductivity is 25 W/(m·K) or higher. Preferably, the die for hot working has a nitrided layer on a work surface.

[0014] Still another aspect of the present invention is a manufacturing method for a die for hot working, in which the steel for a hot working die is quenched at a quenching temperature of 1020-1080°C and tempered at a tempering temperature of 540-620°C.

[0015] Preferably, after the quenching and the tempering, a nitriding treatment is further carried out on a work surface.

[Advantageous Effects of Invention]

[0016] According to the present invention, a steel for a die optimal for hot working can be obtained. In addition, the use of this steel for a die makes it possible to provide a die for hot working having both high hardness and high thermal conductivity and maintaining the high hardness and a manufacturing method for the same.

[Brief Description of Drawings]

[0017]

Fig. 1 is a graph figure showing hardness at each tempering temperature of a steel for a die of each of the present invention examples and comparative examples quenched and then tempered at 500-650°C.

Fig. 2 is a graph figure showing thermal conductivity of the steel for a die of each of the present invention examples and the comparative examples quenched and then tempered to hardness of 45-52 HRC.

[Description of Embodiments]

[0018] A feature of the present invention is that it was found that there is a compositional makeup of a steel for a die optimal for achieving high hardness and high thermal conductivity of a die for hot working at the same time when the fact that a die for hot working is produced by quenching and tempering a steel for a die or by carrying out a nitriding treatment on a work surface thereof is taken into account. In particular, the feature is that it was found that there is an optimal makeup for achieving a high hardness of 52 HRC or higher and high thermal conductivity of 25 W/(m·K) or higher at the same time.

[0019] In addition, the feature is that optimal quenching and tempering conditions for achieving high hardness and high thermal conductivity at the same time in this optimal compositional makeup of a steel for a die was found. In particular, the feature is that, when the tempering temperature is set within a temperature range of 540-620°C (preferably to near 575°C), a steel for a die of the present invention having the optimal compositional makeup is capable of achieving a high hardness of 52 HRC or higher, and thus a die is not easily softened (the degree of softening is small) in spite of a subsequent nitriding treatment or a temperature-rising environment during use.

[0020] A die for hot working of the present invention can be applied to, for example, a die for hot forging, a die for die casting, a hot extrusion die and a die for hot stamping and is preferably applied to, in particular, a die for hot stamping. Hereinafter, each configuration condition of the present invention will be described.

[0021] The steel for a hot working die of the present invention has a compositional makeup containing, in mass% (hereinafter, simply expressed as "%"), 0.45-0.65% of C, 0.1-0.6% of Si, 0.1-2.5% of Mn, 1.0-6.0% of Cr, 1.2-3.5% of (Mo+1/2W) where Mo and W are contained independently or in combination, 0.1-0.5% of V, 0.15-0.6% of Ni, 0.1-0.6% of Cu, and 0.1-0.6% of Al, a balance being Fe and inevitable impurities.

· C: 0.45-0.65%

[0022] C is an element that forms a solid solution in a basis material (matrix) by quenching to improve the hardness of dies. In addition, C is an element that forms a carbide with a carbide-forming element such as Cr, Mo or V, which will be described below, to improve the hardness of dies. However, when the amount of C is too large, the toughness of dies deteriorates due to the coarsening of a primary carbide or the like. Therefore, the amount of C is set to 0.45-0.65%. The amount of C is preferably 0.47% or more. The amount of C is more preferably 0.49% or more. In addition, the amount of C is preferably 0.63% or less. The amount of C is more preferably 0.60% or less. The amount of C is still more preferably 0.58% or less.

• Si: 0.1-0.6%

[0023] Si is used as a deoxidizing agent in a smelting step. In addition, Si is an element that forms a solid solution in the basis material to improve the hardness of dies. However, when Si is too large, after smelting, a segregation tendency in steel becomes strong, and a solidified structure also becomes coarse, which leads to the toughness deterioration of dies. In addition, Si is an element that significantly decreases the thermal conductivity of dies after quenching and tempering. Therefore, the amount of Si is set to 0.1-0.6%. The amount of Si is preferably 0.14% or more. The amount of Si is more preferably 0.17% or more. In addition, the amount of Si is preferably 0.45% or less and more preferably 0.4% or less. The amount of Si is still more preferably 0.35% or less. The amount of Si is far still more preferably 0.3% or less.

• Mn: 0.1-2.5%

[0024] Mn is used as a deoxidizing agent or a desulfurization agent in the smelting step. In addition, Mn is an element that contributes to the strengthening of the basis material and improvement in hardenability and toughness after quenching and tempering. However, when Mn is too large, the thermal conductivity of dies significantly decreases. Therefore, the amount of Mn is set to 0.1-2.5%. The amount of Mn is preferably 0.15% or more. In addition, the amount of Mn is preferably 1.0% or less. The amount of Mn is more preferably 0.35% or less. The amount of Mn is still more preferably 0.32% or less. The amount of Mn is far still more preferably 0.3% or less.

· Cr: 1.0-6.0%

[0025] Cr is an element that forms a solid solution in the basis material to increase hardness. In addition, Cr is an element that increases hardness by forming a carbide and an element that, similar to Mo and V, which will be described below, contributes to secondary curing during tempering. Particularly, Cr is an element capable of increasing tempering softening resistance (capable of decreasing the decrease rate of hardness obtained by secondary curing even when the tempering temperature is set to be high) compared with Mo and V. Normally, dies are adjusted to operation hardness by carrying out quenching and tempering on a steel for the dies, and thus an increase in the tempering temperature is effective for increasing the thermal conductivity of dies for hot working. In addition, in the present invention, when the Cr content is set to 1.0% or more, hardness of 52 HRC or higher can be achieved even in a case where the tempering temperature is high, and a die for hot working having thermal conductivity of 25 W/(m·K) or higher can be obtained. In addition, it is also possible to obtain a die for hot working that maintains the above-described hardness and, furthermore, improves in thermal conductivity up to 28 W/(m·K) or higher. The hardness and thermal conductivity are values measured at room temperature (normal temperature).

[0026] In addition, when the Cr content is set to be large, since the nitriding characteristics of the steel for a die can be improved, it is possible to improve the wear resistance of dies (hardness of work surfaces) while maintaining the hardness of the dies due to the improvement in the softening resistance by, for example, further carrying out a nitriding treatment on the work surfaces of the quenched and tempered dies.

[0027] However, when the Cr content is too large, it becomes difficult to increase the thermal conductivity of dies due to the fact itself that the amount of an alloy in the steel for a die becomes large. Therefore, the amount of Cr is set to 1.0-6.0%. The amount of Cr is preferably 1.5% or more. The amount of Cr is more preferably 2.0% or more. In addition, the amount of Cr is preferably 5.5% or less, more preferably 4.8% or less and still more preferably less than 4.5%. In addition, in a case where emphasis needs to be placed on improvement in, particularly, the thermal conductivity, the amount of Cr can also be set to 4.0% or less or 3.5 or less.

• (Mo+1/2W) where Mo and W are contained independently or in combination: 1.2-3.5%

[0028] Mo and W are, similar to Cr, elements that form a solid solution in the basis material to increase hardness, in addition, elements that increase hardness by forming a carbide and elements that contribute to secondary curing during tempering. In addition, Mo and W are elements that improve hardenability. Since W is approximately twice the atomic weight of Mo, can be regulated as (Mo+1/2W) (it is needless to say that only any one may be added or both can be added). However, when the Mo or W content is too large, the thermal conductivity of dies become low due to the fact itself that the amount of an alloy in the steel for a die becomes large. Therefore, Mo and W are set to 1.2-3.5% in terms of the Mo-equivalent relational formula of (Mo+1/2W). The amount of Mo and W is preferably 1.5% or more. The amount of Mo and W is more preferably 1.7% or more. The amount of Mo and W is still more preferably 1.9% or more. In addition, the amount of Mo and W is preferably 3.4% or less. The amount of Mo and W is more preferably 3.2% or less.

[0029] In the case of the present invention, since W is an expensive element, it is possible to replace all of W with Mo. At this time, Mo: 1.2-3.5% is satisfied (which is also true for the preferable ranges). However, W can be contained as an impurity.

• V: 0.1-0.5%

[0030] V is, similar to Cr, an element that increases hardness by forming a carbide and an element that contributes to secondary curing during tempering. However, when the amount of V is too large, the thermal conductivity of dies become low due to the fact itself that the amount of an alloy in the steel for a die becomes large. Particularly, in the present embodiment, since the thermal conductivity tends to become low due to an influence of Ni, Cu and Al added to improve the strength characteristics of dies as described below, it is important to limit V to 0.1-0.5% to satisfy both high thermal conductivity and a high hardness characteristic. The amount of V is preferably 0.2% or more. In addition, the amount of V is preferably 0.45% or less and more preferably 0.4% or less.

• Ni: 0.15-0.6%

[0031] Ni is an element that contributes to toughness improvement of dies. In addition, in the present embodiment, Ni bonds to Al to form and precipitate a Ni-Al-based intermetallic compound and is capable of improving the strength characteristic of the steel for a die by secondary curing. However, when the amount of Ni is too large, since there is a possibility that the thermal conductivity may become significantly low due to an increase in the amount of an alloy in the steel for a die, the amount of Ni is set to 0.15-0.6%. The amount of Ni is preferably 0.2% or more. In addition, the amount of Ni is preferably 0.5% or less and more preferably 0.45% or less.

• Cu: 0.1-0.6%

[0032] Cu is also an element that, similar to Ni, bonds to Al to form and precipitate an intermetallic compound and is capable of improving the strength characteristic of the steel for a die by secondary curing. However, when the amount of Cu is too large, similar to Ni, the thermal conductivity of dies become low due to the fact itself that the amount of an alloy in the steel for a die becomes large. Therefore, the amount of Cu is set to 0.1-0.6%. The amount of Cu is preferably 0.2% or more. In addition, the amount of Cu is preferably 0.5% or less and more preferably 0.45% or less.

· Al: 0.1-0.6% or less

[0033] As described above, Al bonds to Ni or Cu to form an intermetallic compound. When this Al content is too small, since the intermetallic compound is not sufficiently formed, the strength improvement effect cannot be obtained, and, on the other hand, when the Al content is too large, there is a possibility that the thermal conductivity of dies may significantly decrease. Therefore, the amount of Al is set to 0.1-0.6%. The amount of Al is preferably 0.2% or more. In addition, the amount of Al is preferably 0.5% or less and more preferably 0.4% or less.

[0034] Furthermore, in the present embodiment, in order to form and precipitate the intermetallic compound in appropriate quantities, Ni/Al is preferably 1.0-2.0. A more preferably upper limit of Ni/Al is 1.7, and a still more preferable upper limit is 1.5.

[0035] Alternatively, furthermore, in the present embodiment, in order to form and precipitate the intermetallic compound in appropriate quantities, Cu/Al is preferably 1.0-2.0. A more preferably upper limit of Cu/Al is 1.7, and a still more preferable upper limit is 1.5.

• Balance being Fe and inevitable impurities

[0036] When the fact that an increase in the amount of an alloy in the steel for a die decreases the thermal conductivity of dies is taken into account, it is preferable that the balance other than the above-described elemental species is substantially Fe. Elemental species that are not clearly mentioned here (for example, elemental species such as P, S, Ca, Mg, O (oxygen) and N (nitrogen)) are elements that possibly remain in steel inevitably, and these elements are allowed to be contained as impurities. At this time, when P is too large, P is segregated in prior austenite grain boundaries during a heat treatment such as tempering, and the toughness of dies deteriorates. Therefore, the amount of P is preferably regulated to be 0.05% or less. The amount of P is more preferably regulated to be 0.03% or less. In addition, when S is too large, hot workability deteriorates at the time of blooming an ingot or the like. Therefore, S is preferably regulated to be 0.01% or less. The amount of S is more preferably regulated to be 0.008% or less.

[0037] When a steel for a die having the above-described compositional makeup is quenched and tempered, it is possible to obtain the die for hot working of the present invention that is excellent in terms of hardness and thermal conductivity. The hardness of the die for hot working of the present invention is a value measured at room temperature (normal temperature), and it is possible to achieve sufficient hardness, for example, 52 HRC or higher and to impart excellent wear resistance to the die. In addition, the hardness of the die can be preferably set to 53 HRC or higher by adjusting the tempering temperature.

[0038] In the present invention, there is no need to regulate the upper limit of the hardness of the die. However, in the case of steels for a die having the above-described compositional makeup, the upper limit is, realistically, approximately 60 HRC based on the peak hardness of secondary curing (roughly within a tempering temperature range of 540-620°C). In addition, regardless of the fact that the peak hardness of secondary curing is approximately 60 HRC, the upper limit of this hardness is preferably set to 58 HRC or lower since, that is, the tempering temperature can be raised beyond the peak hardness (that is, the thermal conductivity can be increased).

[0039] In addition, when a steel for a die having the above-described compositional makeup is quenched and tempered to adjust the hardness of a die to 52 HRC, the thermal conductivity of the die of the present embodiment is 25 W/(m·K) or higher. This thermal conductivity is a value measured at room temperature (normal temperature). The thermal conductivity is preferably 28 W/(m·K) or higher. In a case where it is necessary to further increase the thermal conductivity of the die of the present invention having the above-described thermal conductivity, the thermal conductivity can be further increased by setting the hardness to less than 52 HRC. In addition, it is also possible to adjust the hardness of the die to higher than 52 HRC once the die has sufficient thermal conductivity. Specifically, when the hardness of the die is 45 HRC or higher and 48 HRC or lower, the thermal conductivity is preferably 30 W/(m·K) or higher, more preferably 32 W/(m. K) or higher and still more preferably 34 W/(m·K) or higher. In addition, when the hardness of the die is 53 HRC or higher and 55 HRC or lower, the thermal conductivity is preferably 25 W/(m·K) or higher and more preferably 27 W/(m·K) or higher.

[0040] Such a die can be achieved with a steel for a die having a heat treatment characteristic that exhibits hardness of 52 HRC or higher when tempered at 575°C. At the time of confirming this heat treatment characteristic, the quenching temperature before tempering can be set to, for example, 1030°C. In addition, the steel for a die of the present invention has the above-described heat treatment characteristic. Therefore, in dies that are being used in, for example, the hot stamping method (for example, 100-400°C), it is possible to maintain high hardness, and it is also possible to maintain high thermal conductivity.

[0041] In the case of the present invention, there is no need to specify the upper limit of the thermal conductivity of the die. However, when the fact that the hardness of the die is decreased by increasing the tempering temperature (for example, adjusting the tempering temperature to a temperature of higher than 600°C) is taken into account, the upper limit is, realistically, approximately 50 W/(m·K). The upper limit is preferably 47 W/(m·K) or lower. The upper limit is more preferably 45 W/(m·K) or lower. In addition, when the hardness of the die is maintained at 52 HRC or higher, the upper limit of the thermal conductivity is, realistically, approximately 40 W/(m·K). The upper limit is preferably 38 W/(m·K) or higher.

[0042] The die for hot working of the present invention preferably has a nitrided layer on a work surface.

[0043] As described above, the die for hot working of the present invention has both high hardness and high thermal conductivity. In addition, when this die further has a nitrided layer on the work surface, it is possible to further improve the wear resistance of the die (the hardness of the work surface). In addition, it is also possible to suppress a decrease in the hardness of the die main body at the time of a nitriding treatment due to the quenching and tempering characteristics of the steel for a die of the present invention. The work surface refers to a surface of the die that comes into contact with a workpiece during hot working.

[0044] In a manufacturing method for a die for hot working of the present invention, the steel for a die is quenched and tempered.

[0045] When the steel for a die having the above-described compositional makeup is quenched and tempered, the quenching temperature varies with the target hardness or the like and can be set to, for example, approximately 1020-1080°C. The quenching temperature is preferably 1050°C or lower.

[0046] In addition, the steel for a die quenched at this quenching temperature is tempered at a tempering temperature of, for example, 540-620°C, whereby it is possible to obtain a die having thermal conductivity of 25 W/(m·K) or higher while stably achieving hardness of 52 HRC or higher. At this time, the upper limit of the tempering temperature is preferably set to approximately 600°C on the condition that hardness of 52 HRC or higher is maintained. The upper limit is more preferably 595°C or lower. The upper limit is still more preferably 590°C or lower. In addition, the lower limit of the tempering temperature is preferably set to approximately 550°C. The lower limit is more preferably 555°C or higher. The lower limit is still more preferably 560°C or higher.

[0047] When a heat treatment characteristic enabling hardness of 52 HRC or higher to be achieved at a tempering temperature near 575°C, at which the peak hardness of secondary curing is exhibited, is regarded as a standard, the steel for a die of the present invention satisfying this standard of the heat treatment characteristic is capable of maintaining hardness of 45 HRC or higher even in a broad tempering temperature range of 540-620°C. In addition, when the above-described peak hardness is higher than 52 HRC, for example, 53 HRC or higher, 54 HRC or higher or 55 HRC or higher, it is possible to maintain hardness of 52 HRC or higher in a broad tempering temperature range. In addition, it is possible to obtain thermal conductivity of 25 W/(m·K) or higher in a broad tempering temperature, which makes it possible to improve the thermal conductivity at tempering temperatures of, particularly, 575°C or higher.

[0048] The steel for a die of the present invention can be made into a die for hot working having predetermined hardness by quenching and tempering. In addition, during these processes, the steel for a die can be made into a shape of the die for hot working by a variety of machining such as cutting or perforation. Regarding the timing of this machining, the machining can be carried out in a state where the hardness is low before quenching and tempering (that is, in an annealed state). In addition, in this case, finishing may also be carried out after quenching and tempering. In addition, depending on the situation, the above-described machining may be carried out together with the finishing in a pre-hardened state after quenching and tempering.

[0049] In the manufacturing method for a die for hot working of the present invention, preferably, a nitriding treatment is further carried out on the work surface of the die on which the above-described quenching and tempering have been carried out.

[0050] As described above, when the steel for a die having the above-described compositional makeup is quenched and tempered, it is possible to obtain a die having thermal conductivity of 25 W/(m·K) or higher when, for example, the hardness has been adjusted to 52 HRC. In addition, since the steel for a die having the above-described compositional makeup is also excellent in terms of a nitriding characteristic, when a nitriding treatment is further carried out on the work surface of the die that has been quenched and tempered as described above, it is possible to improve the wear resistance of the die (the hardness of the work surface). In addition, it is also possible to suppress a decrease in the hardness of the die main body at the time of the nitriding treatment due to the quenching and tempering characteristics of the steel for a die of the present invention. At this time, as the conditions for the nitriding treatment, for example, conditions for a variety of known nitriding treatments such as a gas nitriding treatment or a salt bath nitriding treatment can be applied.

Example 1

[0051] Ten-kilogram ingots having a compositional makeup in Table 1 were smelted. In addition, these ingots were heated to 1160°C, cogged with a hammer and then left to be cooled, an annealing treatment was carried out on these cooled steel materials at 870°C, thereby producing steels Nos. 1-6 that were present invention examples and steels Nos. 7-9 that were comparative examples.

[Table 1]

Specimen No.	C	Si	Mn	Cr	Mo	V	Ni	Cu	Al	Fe*	Note
No. 1	0.55	0.20	0.35	2.10	3.20	0.40	0.45	0.30	0.34	Bal.	Present Invention Example
No. 2	0.55	0.20	0.35	2.10	3.20	0.40	0.30	0.30	0.25	Bal.	
No. 3	0.55	0.20	0.35	2.10	3.20	0.40	0.15	0.13	0.11	Bal.	
No. 4	0.60	0.25	0.25	1.70	2.00	0.40	0.30	0.30	0.25	Bal.	
No. 5	0.55	0.25	0.25	1.70	3.20	0.40	0.30	0.30	0.25	Bal.	
No. 6	0.60	0.25	0.25	1.70	3.20	0.40	0.30	0.30	0.25	Bal.	
No. 7	0.55	0.20	0.35	2.10	3.20	0.40	<0.10	<0.10	<0.10	Bal.	Comparative Example
No. 8	0.55	0.25	0.25	1.70	2.00	0.40	<0.10	<0.10	<0.10	Bal.	
No. 9	0.55	0.25	0.25	1.70	3.20	0.40	<0.10	<0.10	<0.10	Bal.	
* P≤0.05%, S≤0.01%											

<Evaluation of tempered hardness>

[0052] The steels for a die Nos. 1-9 were quenched at a quenching temperature of 1030°C. At this time, as cooling conditions, cooling rates when the steels for a die, which are referred to as present invention steels and comparative steels, were as large as an actual die for hot stamping were assumed, and the half cooling time was set to 40 minutes (the half cooling time refers to a time required to cool a workpiece from the quenching temperature to a temperature of (quenching temperature + room temperature)/2). In addition, the quenched steels for a die were tempered at tempering temperatures of 500-650°C. The tempering was carried out twice, and the steels were held at each temperature for two hours. The tempering temperatures were set to a total of seven conditions at 25°C intervals. In addition, for each of Nos. 1-9, Rockwell hardness (C scale) of the central part at room temperature was measured at each tempering temperature. The results are shown in Fig. 1 to Fig. 3.

[0053] Nos. 1-7, which were the present invention examples, achieved the tempered hardness of 52 HRC or higher within a tempering temperature range of 550-600°C. In contrast, Nos. 7-9, which were the comparative examples, all had tempered hardness of lower than 52 HRC within a tempering temperature range of 500-650°C.

<Evaluation of thermal conductivity>

[0054] Subsequently, the thermal conductivity of Nos. 1-9 was measured. The tempered hardness values of specimens at the time of measuring the thermal conductivity were 52 HRC for Nos. 1 to 6, which were the present invention examples, and 51 HRC, 50 HRC and 45 HRC for Nos. 7, 8 and 9, which were the comparative examples, respectively. Regarding the measurement procedure, first, dies were worked into test pieces having a disc shape that was 10 mm in diameter and 2 mm in thickness, and the thermal diffusivity and specific heat of these test pieces were measured by the laser flash method. In addition, the thermal conductivity at room temperature was calculated from the following formula using the values of the measured thermal diffusivity and specific heat. The results are shown in Fig. 2.

$$\text{Thermal conductivity } \lambda\ (\mathrm{W/(m\cdot K)}) = \rho\cdot\alpha\cdot C_p$$

(ρ: density at room temperature, α: heat diffusivity, C_p: specific heat)

[0055] From the results of Fig. 2, it was confirmed that Nos. 1 to 6, which were the present invention examples, achieved thermal conductivity of 25 W/(m·K) or higher. On the other hand, Nos. 7 to 9, which were the comparative examples, had the same level of thermal conductivity as the present invention, but originally had peak hardness that did not reach 52 HRC. Therefore, when thermal conductivity is adjusted (specifically, when the tempering temperature is increased to increase thermal conductivity) in steels for a die like the comparative examples, hardness further decreases, and it is not possible to cope with dies with a variety of required characteristics. In contrast, it was possible to confirm that the steels for a die of the present invention examples had not only sufficient peak hardness but also excellent tempering softening resistance and thus the present invention examples having both high thermal conductivity and a high hardness characteristic had advantageous characteristics in uses for dies for hot working.

Claims

1. A steel for a hot working die having a compositional makeup containing, in mass%, 0.45-0.65% of C, 0.1-0.6% of Si, 0.1-2.5% of Mn, 1.0-6.0% of Cr, 1.2-3.5% of (Mo+1/2W) where Mo and W are contained independently or in combination, 0.1-0.5% of V, 0.15-0.6% of Ni, 0.1-0.6% of Cu, and 0.1-0.6% of Al, a balance being Fe and inevitable impurities.

2. The steel for a hot working die according to Claim 1,
wherein, when the steel has been tempered at 575°C, a hardness is 52 HRC or higher.

3. A die for hot working having a compositional makeup containing, in mass%, 0.45-0.65% of C, 0.1-0.6% of Si, 0.1-2.5% of Mn, 1.0-6.0% of Cr, 1.2-3.5% of (Mo+1/2W) where Mo and W are contained independently or in combination, 0.1-0.5% of V, 0.15-0.6% of Ni, 0.1-0.6% of Cu, and 0.1-0.6% of Al, a balance being Fe and inevitable impurities.

4. The die for hot working according to Claim 3,
wherein a hardness is 52 HRC or higher, and a thermal conductivity is 25 W/(m·K) or higher.

5. The die for hot working according to Claim 3 or 4, comprising:
a nitrided layer on a work surface.

6. A manufacturing method for a die for hot working,
wherein the steel for a hot working die according to Claim 1 or 2 is quenched at a quenching temperature of 1020-1080°C and tempered at a tempering temperature of 540-620°C.

7. The manufacturing method for a die for hot working according to Claim 6,
wherein, after the quenching and the tempering, a nitriding treatment is further carried out on a work surface.

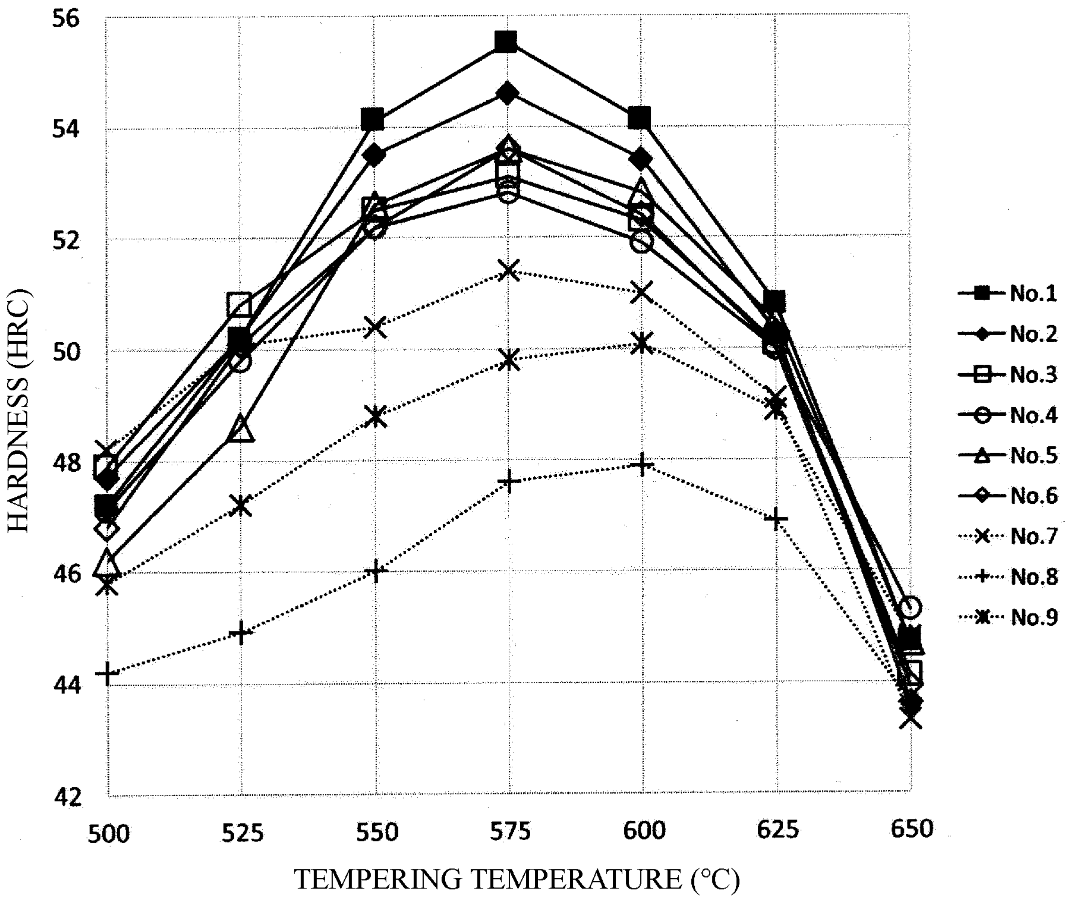
HARDNESS (HRC)
56
54
52
50
48
46
44
42
500
525
550
575
600
625
650
TEMPERING TEMPERATURE (°C)
No.1
No.2
No.3
No.4
No.5
No.6
No.7
No.8
No.9

FIG. 1

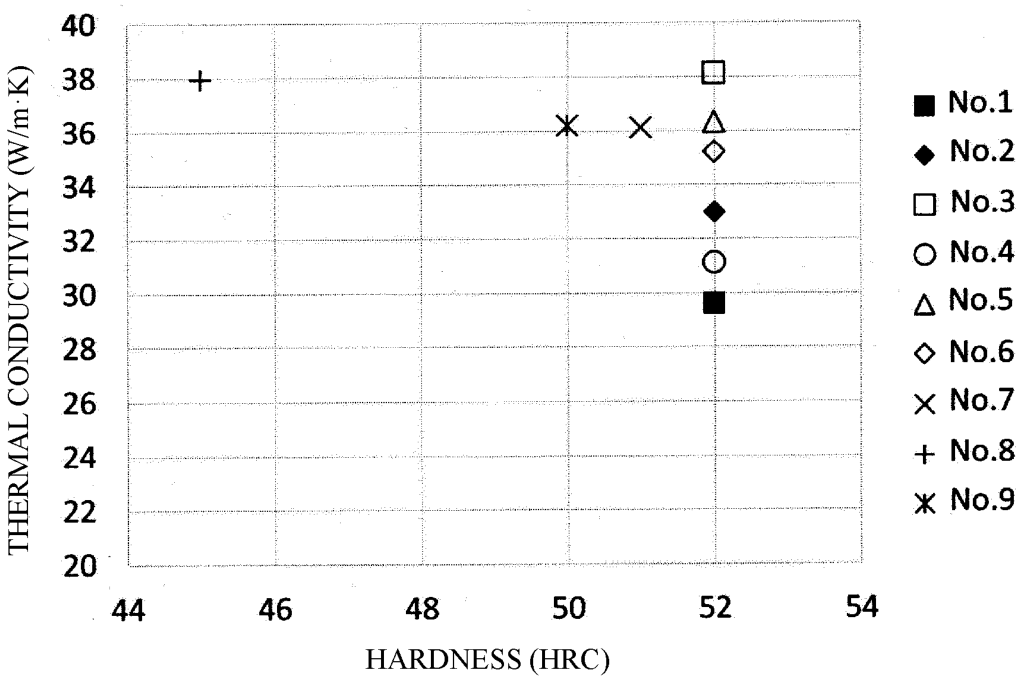
THERMAL CONDUCTIVITY (W/m·K)
40
38
36
34
32
30
28
26
24
22
20
44
46
48
50
52
54
HARDNESS (HRC)
No.1
No.2
No.3
No.4
No.5
No.6
No.7
No.8
No.9

FIG. 2

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2021/010616

A. CLASSIFICATION OF SUBJECT MATTER

C22C 38/00(2006.01)i; C21D 1/06(2006.01)i; C21D 9/00(2006.01)i; C22C 38/58(2006.01)i
FI: C22C38/00 301H; C21D1/06 A; C21D9/00 M; C22C38/00 302E; C22C38/58

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
C22C38/00-38/60; C21D1/06; C21D9/00

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Published examined utility model applications of Japan	1922-1996
Published unexamined utility model applications of Japan	1971-2021
Registered utility model specifications of Japan	1996-2021
Published registered utility model applications of Japan	1994-2021

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y	JP 2017-043814 A (DAIDO STEEL CO., LTD.) 02 March 2017 (2017-03-02) claims, paragraphs [0044], [0046], [0055]-[0074]	1-4, 6 5, 7
X Y A	JP 2009-242319 A (DAIDO STEEL CO., LTD.) 22 October 2009 (2009-10-22) claims, paragraphs [0042], [0009], [0075], [0078]-[0112]	1-3, 6 5, 7 4
Y	JP 2020-026567 A (HITACHI METALS, LTD.) 20 February 2020 (2020-02-20) claims, paragraph [0030]	5, 7
A	JP 2009-120886 A (KOBE STEEL, LTD.) 04 June 2009 (2009-06-04)	1-7
P, X P, A	JP 2021-011618 A (SANYO SPECIAL STEEL CO., LTD.) 04 February 2021 (2021-02-04) claims, paragraphs [0038]-[0056]	1-4, 6 5, 7

☐ Further documents are listed in the continuation of Box C.　☒ See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
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"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
20 May 2021 (20.05.2021)	01 June 2021 (01.06.2021)
Name and mailing address of the ISA/ Japan Patent Office 3-4-3, Kasumigaseki, Chiyoda-ku, Tokyo 100-8915, Japan	Authorized officer Telephone No.

Form PCT/ISA/210 (second sheet) (January 2015)

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application no.
PCT/JP2021/010616

Patent Documents referred in the Report	Publication Date	Patent Family	Publication Date
JP 2017-043814 A	02 Mar. 2017	US 2017/0058385 A1 claims, paragraphs [0074]-[0075], [0078]-[0079], [0089]-[0106] EP 3135777 A1 CN 106480370 A KR 10-2017-0026220 A TW 201713785 A	
JP 2009-242819 A	22 Oct. 2009	(Family: none)	
JP 2020-026567 A	20 Feb. 2020	(Family: none)	
JP 2009-120886 A	04 Jun. 2009	US 2010/0135844 A1 WO 2009/063690 A1 CN 101668874 A TW 200936785 A	
JP 2021-011618 A	04 Feb. 2021	(Family: none)	

Form PCT/ISA/210 (patent family annex) (January 2015)

REFERENCES CITED IN THE DESCRIPTION

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- JP 2017043814 A **[0006]**
- JP 2018024931 A **[0006]**
- JP 5744300 B **[0006]**
- JP 2017053023 A **[0006]**