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(54) **STEEL PLATE FOR HOT STAMPING**

(57) A steel plate for hot stamping contains, in % by mass, C: 0.25% or more and 0.4% or less, Si: 1.05% or more and 1.4% or less, Mn: 0% or more and 1.4% or less, Cr: 0.6% or more and 3.0% or less, P: 0% or more and 0.03% or less, S: 0% or more and 0.02% or less, Al: 0.01% or more and 1% or less, N: 0% or more and 0.01% or less, B: 0.0005% or more and 0.005% or less, Ti:

0.005% or more and 0.1% or less, and iron and inevitable impurities as remainder. This steel plate for hot stamping exhibits excellent hardness stability in addition to a balance between strength and toughness as a relational expression of $[C] + 2/9[Si] + 7/9[Mn] + 8/9[Cr] - 7/4 > 0$ is satisfied.

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Description**Technical Field**

5 [0001] The present invention relates to a steel plate for hot stamping.

Background Art

10 [0002] In recent years, there has been a demand for improvement in collision safety of motor vehicles, and in association with this, there has been a demand for a further increase in strength of steel plates for hot stamping used in parts required to exhibit rigidity of motor vehicles. However, when the strength of steel plate is improved, the low temperature toughness deteriorates and the balance between strength and toughness is thus lost. In order to cope with this problem, Non Patent Literature 1 proposes that the balance between strength and toughness of a steel plate is improved by refining the former austenite grains after hot stamping.

15 [0003] In hot stamping, the cooling velocity inside the steel plate may decrease by an increase in the die temperature and the clearance between the die and the steel plate. When the cooling velocity of the steel plate is equal to or lower than the critical cooling velocity, soft phases such as ferrite and bainite precipitate and the hardness of the steel plate thus decreases. In particular, as the cooling velocity at a temperature equal to or lower than the Ms point decreases, auto tempering is promoted and this causes a decrease in hardness of the steel plate.

20 [0004] In Non Patent Literature 2, a change in cooling velocity when changing the clearance between the die and the steel plate is examined and it has been indicated that the cooling velocity decreases to about 15°C/s when this clearance is 0.4 mm.

25 [0005] As described in Non Patent Literature 1, there is a method in which the crystal grains of steel are refined as a general structure design technology of steel plates for hot stamping and this method makes it possible to obtain a steel plate having an excellent balance between strength and toughness. As a method for refining the crystal grains, there is a method in which elements such as Nb, Ni, and Ti are added, but the economical efficiency of the steel plate becomes poor in this case. A steel plate having refined crystal grains exhibits poor hardenability and thus lacks hardness stability.

30 [0006] In order to solve this problem, it is also considered to improve process problems that cause a decrease in hardness, such as an increase in die temperature and clearance between the die and the steel plate. However, in that case, it is required to repeatedly modify the die and prepare a special die, and this requires a great deal of labor and cost. Hence, in the conventional steel plates for hot stamping, there is a problem that it is difficult to obtain a member (molded product) having an excellent balance between strength and toughness and excellent hardness stability without increasing labor and cost.

35 **Citation List**

Non Patent Literature

40 [0007] Non Patent Literature 1: Kazuo Hikida et al., "Development of TS 1800 MPa Grade Hot Stamping Steel Sheet" Materia Vol. 52, No. 2, 2013, pp. 68-70

[0008] Non Patent Literature 2: Katsuji Nakashima, "Hardening Technology of Steel by Die Quenching and Application to Body Parts" CAMP-ISIJ Vol. 17 2004, pp. 980-983

Summary of Invention

45 [0009] An object of the present invention is to provide a steel plate for hot stamping which can provide a molded product which exhibits excellent hardness stability in addition to the balance between strength and toughness while suppressing increases in labor and cost in the hot stamping process.

50 [0010] A steel plate for hot stamping according to an aspect of the present invention contains,

in % by mass,
 C: 0.25% or more and 0.4% or less,
 Si: 1.05% or more and 1.4% or less,
 Mn: 0% or more and 1.4% or less,
 55 Cr: 0.6% or more and 3.0% or less,
 P: 0% or more and 0.03% or less,
 S: 0% or more and 0.02% or less,
 Al: 0.01% or more and 1% or less,

N: 0% or more and 0.01% or less,

B: 0.0005% or more and 0.005% or less,

Ti: 0.005% or more and 0.1% or less, and

iron and inevitable impurities as remainder. This steel plate for hot stamping exhibits excellent hardness stability in addition to a balance between strength and toughness as a following relational expression (1) is satisfied, where [C] denotes a C content, [Si] denotes a Si content, [Mn] denotes a Mn content, and [Cr] denotes a Cr content.

[Math. 1]

$$[C] + \frac{2}{9} [Si] + \frac{7}{9} [Mn] + \frac{8}{9} [Cr] - \frac{7}{4} > 0 \quad \dots (1)$$

[0011] According to the present invention, it is possible to provide a steel plate for hot stamping which can provide a molded product which exhibits excellent hardness stability in addition to the balance between strength and toughness while suppressing increases in labor and cost in the hot stamping process.

Brief Description of Drawings

[0012]

FIG. 1 is a graph illustrating the relation between absorbed energy in a Charpy impact test when a flat plate is hardened using a die and hardness when hardening is performed at a cooling velocity of 10°C/s.

FIG. 2 is a diagram schematically illustrating a hot stamping process.

FIG. 3 is a schematic diagram illustrating the respective dimensions of a test piece used in a Charpy pendulum impact test.

FIG. 4 is a schematic diagram illustrating the respective dimensions of a test piece used in a hardness test.

Description of Embodiment

[0013] Hereinafter, a steel plate for hot stamping according to an embodiment of the present invention will be described in detail.

(Steel plate for hot stamping)

[0014] The steel plate for hot stamping according to the present embodiment contains, in % by mass,

C: 0.25% or more and 0.4% or less,

Si: 1.05% or more and 1.4% or less,

Mn: 0% or more and 1.4% or less,

Cr: 0.6% or more and 3.0% or less,

P: 0% or more and 0.03% or less,

S: 0% or more and 0.02% or less,

Al: 0.01% or more and 1% or less,

N: 0% or more and 0.01% or less,

B: 0.0005% or more and 0.005% or less,

Ti: 0.005% or more and 0.1% or less, and

iron and inevitable impurities as remainder.

[0015] This steel plate for hot stamping exhibits excellent hardness stability in addition to a balance between strength and toughness as a following relational expression (1) is satisfied, where [C] denotes a C content, [Si] denotes a Si content, [Mn] denotes a Mn content, and [Cr] denotes a Cr content.

[Math. 1]

$$[C] + \frac{2}{9} [Si] + \frac{7}{9} [Mn] + \frac{8}{9} [Cr] - \frac{7}{4} > 0 \quad \dots (1)$$

[0016] In order to obtain a steel plate for hot stamping which is excellent in both the balance between strength and

toughness and the hardness stability, the present inventors have conducted extensive studies on the component composition of steel plate. From the description in Non Patent Literature 2, it has been expected that the cooling velocity of a normal member fluctuates in a range of 30°C/s to 10°C/s in the hot stamping process due to the clearance between the die and the steel plate and an increase in the die temperature. For this reason, the present inventors have focused on suppression of the variation in hardness even when the cooling velocity fluctuates in addition to the balance between strength and toughness, and conducted detailed investigations on the component system of steel plate for achieving this. As a result, the present inventors have newly found out that the balance between strength and toughness and hardness stability can be both achieved by adjusting the balance among the contents of C, Si, Mn, and Cr so that the relational expression (1) is satisfied as well as each component composition in a steel plate satisfies the above range, and thus conceived the present invention.

[0017] First, each component composition in the steel plate for hot stamping according to the present embodiment will be described in detail.

[C (carbon): 0.25% by mass or more and 0.4% by mass or less]

[0018] The C content determines the strength of the steel plate after die cooling. In order to obtain sufficient strength of the steel plate, the C content is 0.25% by mass or more, preferably 0.255% by mass or more, more preferably 0.260% by mass or more.

[0019] However, when the C content is excessive, the strength of the steel plate after hot rolling may increase and this may lead to cracking during cold rolling and deterioration in weldability. Hence, the C content is 0.4% by mass or less, preferably 0.38 % by mass or less, more preferably 0.36 % by mass or less.

[Si (silicon): 1.05% by mass or more and 1.4% by mass or less]

[0020] Si contributes to the hardness stability of the steel plate by increasing the temper softening resistance. Si also has an effect of preventing scale peeling off after die cooling when the surface of the steel plate is not plated. In order to exert these effects, the Si content is 1.05% by mass or more.

[0021] On the other hand, Si facilitates the generation of retained austenite (γ) and promotes a decrease in yield strength (YS) and segregation of Mn. Hence, the Si content is 1.4% by mass or less, preferably 1.35% by mass or less.

[Mn (manganese): 0% by mass or more and 1.4% by mass or less]

[0022] Mn is one of the important elements contained in the steel plate for hot stamping according to the present embodiment and contributes to an increase in the strength of the steel plate after die cooling by enhancing the hardenability of the steel plate. In order to exert this effect, the Mn content is preferably 0.5% by mass or more, more preferably 0.6% by mass or more, still more preferably 0.8% by mass or more.

[0023] On the other hand, in the investigations to achieve both the strength and toughness of the steel plate after die cooling, it has been confirmed that when Mn is excessive, coarse carbides precipitate during die cooling and brittle fracture is caused when shocking stress is applied to the steel plate in a low temperature environment. Hence, the Mn content is 1.4% by mass or less, preferably 1.35% by mass or less, more preferably 1.30% by mass or less.

[0024] Mn is an element that is inevitably mixed into the steel plate and it is thus difficult to set the Mn content to 0% by mass.

[Cr (chromium): 0.6% by mass or more and 3.0% by mass or less]

[0025] Cr is one of the important elements in the steel plate for hot stamping according to the present embodiment. In the investigations to achieve both the strength and toughness of the steel plate after die cooling, it has been confirmed that Cr contributes to securing of the hardness at a low cooling velocity (for example, 10°C/s) as well as suppression of coarse carbide precipitation during die cooling and thus suppresses brittle fracture when shocking stress is applied to the steel plate in a low temperature environment. In order to exert these effects, the Cr content is 0.6% by mass or more, preferably 0.8% by mass or more, more preferably 1.05% by mass or more.

[0026] On the other hand, when Cr is excessively contained in the steel plate, the strength of the steel plate after hot rolling increases and this leads to cracking of the steel plate during cold rolling and deterioration in pickling property after hot rolling. Hence, the Cr content is 3.0% by mass or less, preferably 2.5% by mass or less.

[P (phosphorus): 0% by mass or more and 0.03% by mass or less]

[0027] From the viewpoint of weldability of the member, toughness, and prevention of surface flaws, it is required to

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regulate the upper limit of P content. Hence, the P content is 0.03% by mass or less, preferably 0.025% by mass or less, more preferably 0.02% by mass or less.

[0028] P is an element that is inevitably mixed into the steel plate and it is thus difficult to set the P content to 0% by mass.

5 [S (sulfur): 0% by mass or more and 0.02% by mass or less]

[0029] S forms MnS to decrease the uniformity of the Mn concentration distribution and also deteriorate the weldability of the steel plate. Hence, the S content is 0.02% by mass or less, preferably 0.018% by mass or less, more preferably 0.015% by mass or less.

10 **[0030]** S is an element that is inevitably mixed into the steel plate as P and it is thus difficult to set the S content to 0% by mass.

[Al (aluminum): 0.01% by mass or more and 1% by mass or less]

15 **[0031]** Al is an element that acts as a deoxidizer. In order to exert this effect, the Al content is 0.01% by mass or more, preferably 0.015% by mass or more.

[0032] However, when Al is excessively contained in the steel plate, the hardness after die cooling decreases and excessive generation of Al_2O_3 deteriorates the low temperature toughness. Hence, the Al content is 1% by mass or less, preferably 0.8% by mass or less, more preferably 0.1% by mass or less. The Al content here means the content of Al(sol.Al) in a solid solution state.

20

[N (nitrogen): 0% by mass or more and 0.01% by mass or less]

[0033] N is an element that is inevitably mixed into the steel plate. When N is excessively contained in the steel plate, the amount of solid solution B in the steel plate decreases as N forms a boride and this leads to deterioration in hardenability. Hence, the N content is 0.01% by mass or less, preferably 0.008% by mass or less, more preferably 0.005% by mass or less.

25

[B (boron): 0.0005% by mass or more and 0.005% by mass or less]

30 **[0034]** B is an important element for improving the hardenability of the steel plate. By adding an appropriate amount of B to the steel plate, the hardenability is enhanced and this makes it possible to stably increase the strength of the steel plate after die cooling. In order to exert this effect, the B content is 0.0005% by mass or more, preferably 0.0010% by mass or more, more preferably 0.0015% by mass or more.

35 **[0035]** On the other hand, when B is excessively contained in the steel plate, a coarse iron-boron compound precipitates and this leads to deterioration in toughness. Hence, the B content is 0.0050% by mass or less, preferably 0.0045% by mass or less, more preferably 0.0030% by mass or less.

[Ti (titanium): 0.005% by mass or more and 0.1% by mass or less]

40 **[0036]** Ti decreases the amount of BN generated in the steel plate by forming TiN. This increases the amount of solid solution B in the steel plate and makes it possible to enhance the hardenability improving effect by B. In order to exert this effect, the Ti content is 0.0050% by mass or more, preferably 0.010% by mass or more, more preferably 0.015% by mass or more.

45 **[0037]** On the other hand, when Ti is excessively contained in the steel plate, a carbide precipitates at the crystal grain boundaries and the hardenability of the steel plate deteriorates. Hence, the Ti content is 0.1% by mass or less, preferably 0.08% by mass or less, more preferably 0.06% by mass or less.

[0038] The steel plate for hot stamping according to the present embodiment may further contain one or more selected from the group consisting of Mo, Nb, and V or one or more selected from the group consisting of Cu and Ni in addition to the above component composition. The ranges of component compositions of these will be described below. These elements are not essential elements in the steel plate for hot stamping of the present invention and may not be added.

50

[Mo (molybdenum): 0% by mass or more and 1.0% by mass or less]

55 **[0039]** Mo is an element that contributes to the improvement in hardenability of the steel plate. In order to exert this effect, the Mo content is preferably 0.01% by mass or more. However, when Mo is excessively contained in the steel plate, the strength of the steel plate before hot molding is increased. In order to prevent this, the Mo content is preferably 1.0% by mass or less.

[Nb (niobium) and V (vanadium): 0% by mass or more and 0.1% by mass or less]

[0040] Nb and V form fine carbides and have the effect of refining the structure of steel by the pinning effect. V also has a secondary hardening action by being precipitated during tempering. In order to exert these effects, the Nb and V contents are both preferably 0.0008% by mass or more.

[0041] However, when Nb and V are excessively contained in the steel plate, coarse carbides are formed and this becomes the starting point of fracture to lead to deterioration in toughness. Hence, the Nb and V contents are both preferably 0.1% by mass or less, more preferably 0.08% by mass or less, still more preferably 0.07% by mass or less.

[Cu (copper) and Ni (nickel): 0% by mass or more and 0.5% by mass or less]

[0042] Cu and Ni are preferably added when it is required to improve the delayed fracture properties of the member. However, when Cu and Ni are excessively contained in the steel plate, flaws may be generated on the surface of the steel plate and finally on the surface of the member. Hence, it is preferable that the Cu and Ni contents are each 0.5% by mass or less and it is more preferable that the sum of the Cu and Ni contents is 0.5% by mass or less.

[0043] The steel plate for hot stamping according to the present embodiment exhibits excellent hardness stability in addition to the balance between strength and toughness as the following relational expression (1) is satisfied by adjustment of the balance among the contents of C, Si, Mn, and Cr. In this relational expression (1), [C] denotes the C content (% by mass) in the steel plate for hot stamping. [Si] denotes the Si content (% by mass) in the steel plate for hot stamping. [Mn] denotes the Mn content (% by mass) in the steel plate for hot stamping. [Cr] denotes the Cr content (% by mass) in the steel plate for hot stamping.

[Math. 1]

$$[C] + \frac{2}{9} [Si] + \frac{7}{9} [Mn] + \frac{8}{9} [Cr] - \frac{7}{4} > 0 \quad \dots (1)$$

[0044] As the relational expression (1) is satisfied as well as the respective component compositions satisfy the component ranges in the claims, the steel plate for hot stamping according to the present embodiment exhibits excellent hardness stability as well as is a steel plate having an excellent balance between the strength after hardening by die cooling and the low temperature toughness. Specifically, the following relational expressions (2), (3), and (4) are all satisfied where, A (J/cm²) denotes the absorbed energy in a Charpy impact test at -40°C when a flat plate is hardened using a die, B(Hv) denotes the hardness when the steel plate for hot stamping is heated to the austenite region, then cooled to room temperature at a cooling velocity of 10°C/s, and hardened, and C(Hv) denotes the hardness when the steel plate for hot stamping is heated to the austenite range, then cooled to room temperature at a cooling velocity of 30°C/s, and hardened.

[Math. 2]

$$B > -4.0A + 627 \quad \dots (2)$$

[0045] [Math. 3]

$$B \geq 516 \quad \dots (3)$$

[0046] [Math. 4]

$$|C - B| \leq 35 \quad \dots (4)$$

[0047] The relational expression (2) is an index of the balance between the strength and toughness of the steel plate newly devised by the present inventors and is an important concept when considering the balance between the strength and toughness of the steel plate for hot stamping. In the course of investigations on the balance between strength and toughness, the present inventors have focused on the hardness when the cooling velocity is 10°C/s and the toughness after die cooling of a flat plate. In the die cooling of a flat plate, ideal cooling conditions in which a clearance is not generated between the die and the steel plate in the hot stamping process are taken into consideration. By using the

relational expression (2), it is possible to more faithfully evaluate the balance between strength and toughness when the steel plate for hot stamping is processed into a member (molded product).

[0048] The graph of FIG. 1 illustrates the relation between the absorbed energy A (horizontal axis) in a Charpy impact test at -40°C when a flat plate is hardened using a die and the hardness B (vertical axis) of the steel plate when being hardened at a cooling velocity of 10°C/s . The straight line (1) in this graph corresponds to the relational expression (2). The straight line (2) in this graph corresponds to an equation of $B = 516$.

[0049] The horizontal axis (A) of the graph of FIG. 1 assumes the toughness at the most brittle portion of the member after die cooling. In other words, when a flat plate is subjected to die cooling, the die and the steel plate are in contact with each other in an ideal state and the cooling velocity is thus high. For this reason, the strength after cooling is high but, on the other hand, the flat plate is extremely brittle. In other words, this horizontal axis has a meaning as toughness at the most brittle portion when the steel plate for hot stamping is molded into a member (molded product).

[0050] On the other hand, the vertical axis (B) of the graph of FIG. 1 assumes the hardness of the most softened portion of the member after die cooling. As described above, in the hot stamping process, a clearance may be generated between the die and the steel plate and the die temperature may rise. For this reason, the member after die cooling has a portion that is cooled at a low cooling velocity and has a low hardness (strength). From the description in Non Patent Literature 2, it is assumed that the minimum cooling velocity during die cooling is about 10°C/s . Hence, this vertical axis has a meaning as hardness (strength) at the most softened portion of the member (molded product) after die cooling. Consequently, by using these two axes, the toughness of the weakest portion when shocking stress is applied to the member after being molded and the strength of the weakest portion when static stress is applied to this member can be evaluated.

[0051] Usually, in the hardness region in which B is 516 Hv or more, the strength and toughness of a steel plate are in a trade-off relation and thus the toughness tends to deteriorate when the strength of the steel plate is improved. In other words, it is difficult to improve both the strength and toughness of a steel plate and it is normal that the distribution of A and B exists in the region below the straight line (1) in the graph of FIG. 1.

[0052] The straight line (2) is one index that indicates the hardness stability. During continuous operation of the die in the hot stamping process, the temperature of the die may rise and a clearance may be generated between the die and the steel plate. Due to these factors, the cooling velocity of the steel plate during hardening decreases and the hardness of the steel plate after being hardened decreases as the cooling velocity decreases. Even in the case of a steel plate in which the balance between strength and toughness is improved by the refinement of crystal grains, it is usually difficult for the hardness when the steel plate is hardened in a low cooling velocity region (10°C/s) to satisfy a range of 516 Hv or more. Hence, even in the case of a steel plate in which the balance between strength and toughness is improved by the refinement of crystal grains, it is normal that the distribution of A and B exists in the region below the straight line (2) in FIG. 1.

[0053] In contrast, as a result of extensive studies conducted by the present inventors, it has been revealed that the distribution of A and B are located in the region above the straight lines (1) and (2) in FIG. 1 in the steel plate for hot stamping which satisfies the relational expression (1). Hence, the steel plate for hot stamping according to the present embodiment exhibits excellent hardness stability in addition to the balance between strength and toughness. In other words, this steel plate for hot stamping has an excellent balance between strength and toughness that satisfies the relational expression (2) and can realize a hardness at a certain degree or more even when being cooled at the minimum cooling velocity of 10°C/s .

[0054] The relational expression (4) is another index of the hardness stability of steel plate. When the die temperature rises or a clearance is generated between the die and the steel plate during hot stamping, the cooling velocity of the steel plate may decrease and the hardness of the steel plate after being hardened may become unstable. As described above, it is usually difficult to satisfy the relational expression (4) since the hardness stability decreases when the crystal grains are refined.

[0055] In contrast, as a result of extensive studies conducted by the present inventors, it has been revealed that a hardness exceeding 516 Hv is attained after the steel plate is hardened even in a low cooling velocity region of 10°C/s as well as the difference in hardness between a case having a cooling velocity of 30°C/s and a case having a cooling velocity of 10°C/s is suppressed to 35 Hv or less in the steel plate for hot stamping in which the relational expression (1) is satisfied as well as the respective components satisfy the component ranges in the claims. 30°C/s is an ideal cooling velocity during die cooling, which has been confirmed by an experiment and the like while 10°C/s is the minimum cooling velocity expected as described above. In other words, the relational expression (4) is an index indicating that the difference (variation) in hardness after hardening is small between the upper and lower limits of the cooling velocity assumed in hot stamping. According to the steel plate for hot stamping of the present embodiment, it is possible to stabilize the hardness of the steel plate after being hardened to the extent to which the relational expression (4) is satisfied regardless of the temperature rise of the die and the generation of clearance between the die and the steel plate.

[0056] The steel plate for hot stamping of the present invention may be a base steel plate having a surface not subjected to a plating treatment or a plated steel plate having a surface subjected to a plating treatment.

(Method for manufacturing steel plate for hot stamping)

[0057] Next, a method for manufacturing the steel plate for hot stamping according to the present embodiment will be described.

[0058] First, a slab manufacturing process is performed. In this process, a slab is obtained by melting steel according to a conventional method, pouring the molten steel into a mold, and performing continuous casting. In this process, the component composition of the steel is adjusted during melting so that the compositions of the respective components contained in the slab satisfy the above ranges and the contents of C, Si, Mn, and Cr satisfy the relational expression (1).

[0059] Next, a hot rolling process is performed. In this process, the slab obtained in the above process is first disposed in a heating furnace, heated to a predetermined temperature (for example, 1200°C), and held at the heating temperature for a predetermined time (for example, 30 minutes).

[0060] Next, the heated slab is placed upstream of the hot rolling line. Thereafter, the slab is rolled into a steel plate having a predetermined thickness by allowing the slab to sequentially pass through between the rolls of the rolling stands of the rough rolling mill and the finishing rolling mill and allowing the slab to flow downstream. Thereafter, the steel plate after being hot-rolled is cooled to a predetermined temperature in a cooling apparatus and then wound by a coiler.

[0061] Next, a cold rolling process is performed. In this process, the scale (oxides of iron) generated on the surface of the steel plate in the hot rolling step is first washed off with an acid (pickling) and then the hot-rolled steel plate is further rolled so that the thickness further decreases. Specifically, the hot-rolled steel plate after being subjected to pickling is allowed to pass through between the rolls of the rolling stands so that the hot-rolled steel plate is further thinned. The cold-rolled steel plate obtained by the above processes is the steel plate for hot stamping according to the present embodiment.

(Hot Stamping)

[0062] Next, hot stamping performed using the steel plate manufactured by the above processes will be described with reference to FIG. 2. First, a steel plate for hot stamping 1 manufactured by the above processes is heated in a predetermined heating furnace 2 to a temperature equal to or higher than the austenite transformation temperature. Thereafter, the steel plate for hot stamping 1 after being heated is disposed between dies 3 and 4 and press-molded into a desired shape by the dies 3 and 4. At this time, the steel plate for hot stamping 1 is cooled by coming into contact with the dies 3 and 4, and hardening is performed at the same time as molding. Thereafter, the steel plate after being hardened is taken out from the dies 3 and 4 as a molded product 5 (molded member).

[0063] The molded product 5 has the same component composition as that of the steel plate for hot stamping 1 according to the present embodiment described above and is one in which the balance among the contents of C, Si, Mn, and Cr is adjusted so that the relational expression (1) is satisfied. Hence, the molded product 5 exhibits excellent hardness stability in addition to the balance between strength and toughness and can be utilized in various applications including members for motor vehicles.

[0064] The outline of the above-described embodiment is as follows.

[0065] A steel plate for hot stamping according to the present embodiment contains,

in % by mass,

C: 0.25% or more and 0.4% or less,

Si: 1.05% or more and 1.4% or less,

Mn: 0% or more and 1.4% or less,

Cr: 0.6% or more and 3.0% or less,

P: 0% or more and 0.03% or less,

S: 0% or more and 0.02% or less,

Al: 0.01% or more and 1% or less,

N: 0% or more and 0.01% or less,

B: 0.0005% or more and 0.005% or less,

Ti: 0.005% or more and 0.1% or less, and

iron and inevitable impurities as remainder. This steel plate for hot stamping exhibits excellent hardness stability in addition to a balance between strength and toughness as a following relational expression (1) is satisfied, where [C] denotes a C content, [Si] denotes a Si content, [Mn] denotes a Mn content, and [Cr] denotes a Cr content.

[0066] [Math. 1]

$$[C] + \frac{2}{9} [Si] + \frac{7}{9} [Mn] + \frac{8}{9} [Cr] - \frac{7}{4} > 0 \quad \dots (1)$$

[0067] The steel plate for hot stamping may contain, in % by mass, one or more selected from the group consisting of

Mo: 0% or more and 1.0% or less,
Nb: 0% or more and 0.1 % or less, and
V: 0% or more and 0.1 % or less.

[0068] The steel plate for hot stamping may contain, in % by mass, one or more selected from the group consisting of

Cu: 0% or more and 0.5% or less, and
Ni: 0% or more and 0.5% or less.

Examples

[0069] Hereinafter, the present invention will be described in more detail based on examples. However, the present invention is not limited to the following examples, it is also possible to carry out the present invention by adding changes within a range that is compatible with the above-mentioned and below-mentioned gist, and all of them are included in the technical scope of the present invention.

<Manufacture of steel plate for hot stamping>

[0070] First, a slab was manufactured by melting steel (the remainder being iron and inevitable impurities) having the component composition shown in Nos. 1 to 17 in the following Table 1.

[0071] This molten slab was heated to 1200°C, held for 30 minutes, and then hot-rolled. The finishing temperature was set to 900 ± 20°C, and the finishing plate thickness was set to 2.8 mm. Thereafter, the hot-rolled steel plate was cooled to a winding temperature (CT temperature) at a cooling velocity of 20°C/s to 30°C/s, held at 650°C for 30 minutes, and then cooled in the furnace. Thereafter, the hot-rolled steel plate was subjected to pickling and cold-rolled so that the steel plate had a thickness of 1.4 mm.

<Charpy impact test>

[0072] First, the cold-rolled steel plate fabricated according to the above procedure was cut and hardened. Hardening was performed under the following conditions by a die quench method using a flat plate simulating a die (testing machine: JIS Charpy impact tester (300J)).

[0073] [Hardening conditions]

Steel plate dimensions before hardening: 1.4 mm × 70 mm × 150 mm

Steel plate temperature: 900°C

Steel plate temperature holding time after steel plate reaches 900°C: 100 seconds

Cooling time: about 15 seconds

Die quench start temperature: 700°C

Die quench load: 2000 kgf

Bottom dead center holding time: 30 seconds

[0074] Next, a Charpy pendulum impact test was performed using the cold-rolled steel plate after being subjected to the hardening. This test was performed in conformity with JIS 2242 "Charpy impact test method for metal materials" except the dimensions of the test piece. The dimensions of the test piece used in the present test are as follows. The reference numerals indicating the respective dimensions correspond to the reference numerals illustrated in FIG. 3.

[0075] [Test piece dimensions]

Test piece height h1: 10 mm ± 0.05 mm

Test piece length L: 55 mm ± 0.6 mm

Test piece width b: 1.4 mm ± 0.05 mm

Notch shape: V notch

Notch angle: 45° ± 2°

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Notch bottom radius: $0.25 \text{ mm} \pm 0.025 \text{ mm}$

Height under notch h2: $8 \text{ mm} \pm 0.05 \text{ mm}$

Angle between test piece longitudinal direction and notch symmetry plane: $90^\circ \pm 2^\circ$ Angle between adjacent surfaces eliminating fracture surface: $90^\circ \pm 2^\circ$

[0076] A test piece having the above dimensions was disposed in liquid nitrogen adjusted to have a temperature of $-40^\circ\text{C} \pm 1^\circ\text{C}$ and held for at least 10 minutes. Thereafter, the test piece was taken out from the liquid nitrogen and placed on a support, and an impact was made on the test piece. At this time, the time until the impact was made after the test piece was placed on a support was set to 5 seconds or less.

[0077] A JIS Charpy impact tester (300J) was used as a tester, and an impact blade having a radius of 2 mm was used. The number of test pieces was two, and the average value of two measured values was used for evaluation.

<Evaluation on scale adhesive property>

[0078] Hardening was performed by the die quench method under the same conditions as those in the Charpy impact test described above and then the degree of scale peeling off on the surface of the steel plate was visually confirmed to evaluate the adhesive property of scale. It was evaluated as "○" when the area ratio of the surface of the steel plate in which scale peeling off occurred was 14% or less, and it was evaluated as "×" when the area ratio exceeded 14%.

<Hardness test>

[0079] First, the cold-rolled steel plate fabricated according to the above procedure was processed into a test piece having a shape illustrated in FIG. 4. In FIG. 4, L1 is 10 mm, L2 is 2 mm, L3 is 1.4 mm, L4 is 0.7 mm, L5 is 3 mm, and L6 is 1 mm. Hardening was performed using this test piece under the following conditions.

[0080] [Hardening conditions]

Rate of temperature rise when converting to austenite: 10°C/s

High temperature holding: held at 900°C for 100 seconds

Cooling velocity: constant cooling from 900°C to room temperature at 10°C/s or 30°C/s

[0081] A hardness test was performed using the test piece after being subjected to the hardening in conformity with the "Vickers hardness test method" prescribed in JIS Z 2244. In this test, five points were measured at the positions to be the 1/4 plate thickness from the surface of the test piece at a test load of 9.8 N, and evaluation was performed using the average value of these.

[0082] The following Tables 1 and 2 present each of the component composition (% by mass), absorbed energy A (J/cm^2) in a Charpy impact test at -40°C , Vickers hardness B (Hv) when the cooling velocity is 10°C/s , Vickers hardness C (Hv) when the cooling velocity is 30°C/s , difference in hardness (Hv) between a case having a cooling velocity of 30°C/s and a case having a cooling velocity of 10°C/s , value on the left side of the relational expression (1), value when the right side of the relational expression (2) is subtracted from the left side, and evaluation results on scale adhesive property for each of Nos. 1 to 17 steel plates.

[0083] In the graph of FIG. 1, the respective data for Nos. 1 to 17 steel plates are plotted. The data for Nos. 1 to 9 and 14 to 17 are marked with black circles, and the data for Nos. 10 to 13 are marked with white circles.

[Table 1]

Component composition (% by mass)															
	C	Si	Mn	Cr	P	S	Al	Cu	Ni	Mo	Nb	Ti	N V	B	O
No.1	0.345	1.24	1.23	0.82	0.0100	0.0019	0.041	-	-	-	-	0.022	0.0041	-	0.0005
No.2	0.351	1.22	1.22	1.23	0.0090	0.0011	0.040	-	-	-	-	0.022	0.0044	-	0.0006
No.3	0.337	1.22	0.81	0.82	0.0070	0.0018	0.041	-	-	-	-	0.021	0.0038	-	0.0006
No.4	0.336	1.20	0.81	1.21	0.0090	0.0018	0.040	-	-	-	-	0.021	0.0034	-	0.0009
No.5	0.342	1.22	0.22	1.21	0.0080	0.0009	0.040	-	-	-	-	0.022	0.0044	-	0.0007
No.6	0.326	1.21	0.21	1.52	0.0090	0.0014	0.040	-	-	-	-	0.022	0.0040	-	0.0008
No.7	0.332	1.22	0.21	2.04	0.0100	0.0016	0.039	-	-	-	-	0.022	0.0040	-	0.0007
No.8	0.294	1.19	0.85	0.83	0.0100	0.0010	0.038	-	-	-	-	0.022	0.0047	0.001	-
No.9	0.290	1.19	1.23	0.65	0.0100	0.0020	0.038	-	-	-	-	0.022	0.0039	-	-
No.10	0.289	0.01	0.23	1.24	0.0040	0.0009	0.040	-	-	-	0.004	0.020	0.0009	0.001	0.0009
No.11	0.315	1.24	1.20	0.01	0.0040	0.0010	0.041	-	-	-	-	0.021	0.0041	-	0.0006
No.12	0.326	1.21	1.21	0.01	0.0040	0.0010	0.041	-	-	-	-	0.020	0.0045	-	0.0009
No.13	0.266	1.19	1.21	0.01	0.0040	0.0012	0.041	-	-	-	0.004	0.020	0.0005	0.001	0.0005
No.14	0.271	1.23	1.19	0.60	0.0040	0.0020	0.038	0.10	-	-	-	0.022	0.0043	-	0.0007
No.15	0.294	1.26	1.18	0.61	0.0040	0.0010	0.038		0.10		-	0.021	0.0047	-	0.0007
No.16	0.281	1.24	1.18	0.60	0.0040	0.0020	0.038	0.10	0.10	-	-	0.021	0.0046	-	0.0006
No.17	0.335	1.21	0.82	1.19	0.0040	0.0013	0.036	-	-	0.19	-	0.021	0.0023	-	0.0007

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[Table 2]

	Charpy impact test	Hardness measuring test			[C]+2/9 [Si]+7/9 [Mn]+8/9 [Cr]-7/4	B+4A-627	Scale adhesive property
		Absorbed energy A (J/cm ²)	Hardness B at 10°C/s(Hv)	Hardness C at 30°C/s(Hv)	Hardness difference (Hv)		
No. 1	24.1	594	596	2	0.56	63	○
No. 2	30.4	599	621	22	0.91	93	○
No. 3	30.4	562	575	13	0.22	56	○
No. 4	33.4	578	595	17	0.56	85	○
No. 5	35.7	548	574	26	0.11	64	○
No. 6	39.3	558	566	8	0.36	88	○
No. 7	31.3	570	582	12	0.83	68	○
No. 8	46.4	518	547	28	0.21	77	○
No. 9	37.5	529	542	13	0.34	52	○
No. 10	60.7	325	498	173	-0.18	-59	×
No. 11	42.0	426	564	138	-0.22	-33	○
No. 12	39.3	458	577	119	-0.21	-12	○
No. 13	55.4	379	516	137	-0.27	-27	○
No. 14	51.8	519	519	-1	0.25	100	○
No. 15	43.8	543	533	9	0.28	91	○
No. 16	50.9	526	531	4	0.26	103	○
No. 17	32.1	586	603	17	0.55	88	○

<Discussion>

[0084] The following can be discussed based on Tables 1 and 2.

[0085] In Nos. 1 to 9 and 14 to 17, the contents of C, Si, Mn, and Cr satisfy the relational expression (1) as well as the contents of C, Si, Mn, Cr, P, S, Al, N, B, and Ti in the steel plate each satisfy the ranges in the present invention. In this case, the value of "B + 4A - 627" is a positive value, the relational expression (2) is satisfied, and thus the steel plate has an excellent balance between strength and toughness. Moreover, in Nos. 1 to 9 and 14 to 17, it is "B ≥ 516" and "C

- $B \leq 35$ ", the relational expressions (3) and (4) are also satisfied, and thus the steel plate also exhibits excellent hardness stability. This is clear from the fact that the data (black circles) for Nos. 1 to 9 and 14 to 17 exist in the regions above the straight lines (1) and (2) in the graph of FIG. 1. The evaluation results on the scale adhesive property are all "○".

[0086] In contrast, in Nos. 10 to 13 that do not satisfy the requirements regulated in the present invention, a steel plate excellent in both the balance between strength and toughness and the hardness stability is not obtained as to be described below. As illustrated in the graph of FIG. 1, the data (white circles) for Nos. 10 to 13 all exist in the regions below the straight lines (1) and (2).

[0087] In No. 10, the Si content is less than 1.05% by mass and the value of " $[C] + 2/9[Si] + 7/9[Mn] + 8/9[Cr] - 7/4$ " is a negative value, thus the value of " $B + 4A - 627$ " is a negative value and the balance between strength and toughness is poor. The hardness B when the cooling velocity is 10°C/s is less than 516 Hv, the difference in hardness between a case having a cooling velocity of 30°C/s and a case having a cooling velocity of 10°C/s also exceeds 35 Hv, and the hardness stability is also poor. The evaluation results on the scale adhesive property are also "x".

[0088] In Nos. 11 to 13, the Cr content is less than 0.6% by mass and the value of " $[C] + 2/9[Si] + 7/9[Mn] + 8/9[Cr] - 7/4$ " is a negative value, thus the value of " $B + 4A - 627$ " is a negative value and the balance between strength and toughness is poor. The hardness B when the cooling velocity is 10°C/s is less than 516 Hv, the difference in hardness between a case having a cooling velocity of 30°C/s and a case having a cooling velocity of 10°C/s also exceeds 35 Hv, and the hardness stability is also poor.

[0089] It should be understood that the embodiments and examples disclosed herein are illustrative in all points and not restrictive. The scope of the present invention is shown not by the above description but by the claims, and is intended to include meanings equivalent to the claims and all modifications within the scope.

Claims

1. A steel plate for hot stamping comprising:

in % by mass,

C: 0.25% or more and 0.4% or less,

Si: 1.05% or more and 1.4% or less,

Mn: 0% or more and 1.4% or less,

Cr: 0.6% or more and 3.0% or less,

P: 0% or more and 0.03% or less,

S: 0% or more and 0.02% or less,

Al: 0.01% or more and 1% or less,

N: 0% or more and 0.01% or less,

B: 0.0005% or more and 0.005% or less,

Ti: 0.005% or more and 0.1% or less, and

iron and inevitable impurities as remainder,

wherein the steel plate for hot stamping exhibits excellent hardness stability in addition to a balance between strength and toughness as a following relational expression (1) is satisfied, where [C] denotes a C content, [Si] denotes a Si content, [Mn] denotes a Mn content, and [Cr] denotes a Cr content.

[Math. 1]

$$[C] + \frac{2}{9}[Si] + \frac{7}{9}[Mn] + \frac{8}{9}[Cr] - \frac{7}{4} > 0 \quad \dots (1)$$

2. The steel plate for hot stamping according to claim 1, comprising, in % by mass, one or more selected from the group consisting of

Mo: 0% or more and 1.0% or less,

Nb: 0% or more and 0.1 % or less, and

V: 0% or more and 0.1% or less.

3. The steel plate for hot stamping according to claim 1 or 2, comprising, in % by mass, one or more selected from the group consisting of

Cu: 0% or more and 0.5% or less, and

Ni: 0% or more and 0.5% or less.

FIG. 1

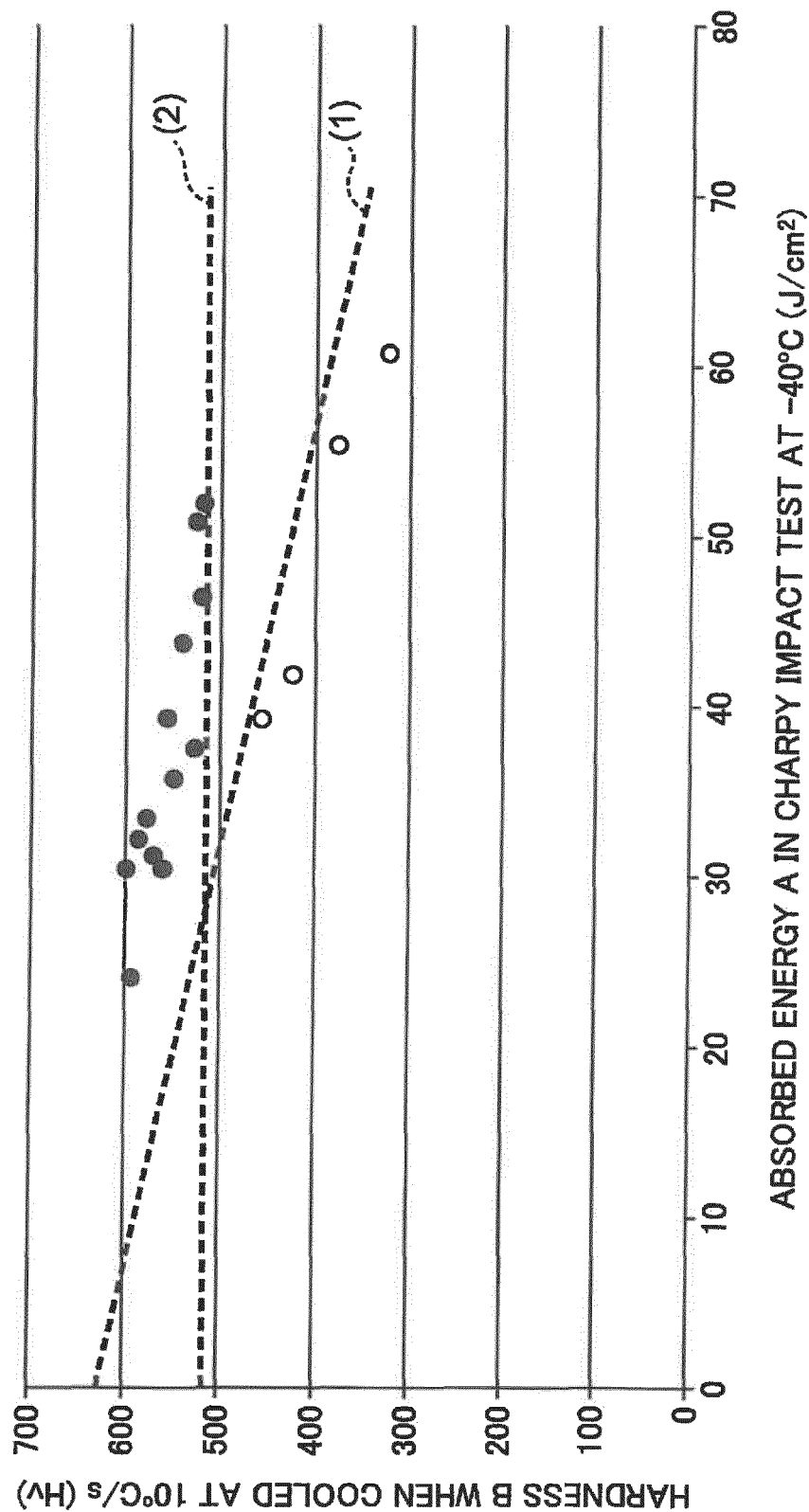


FIG. 2

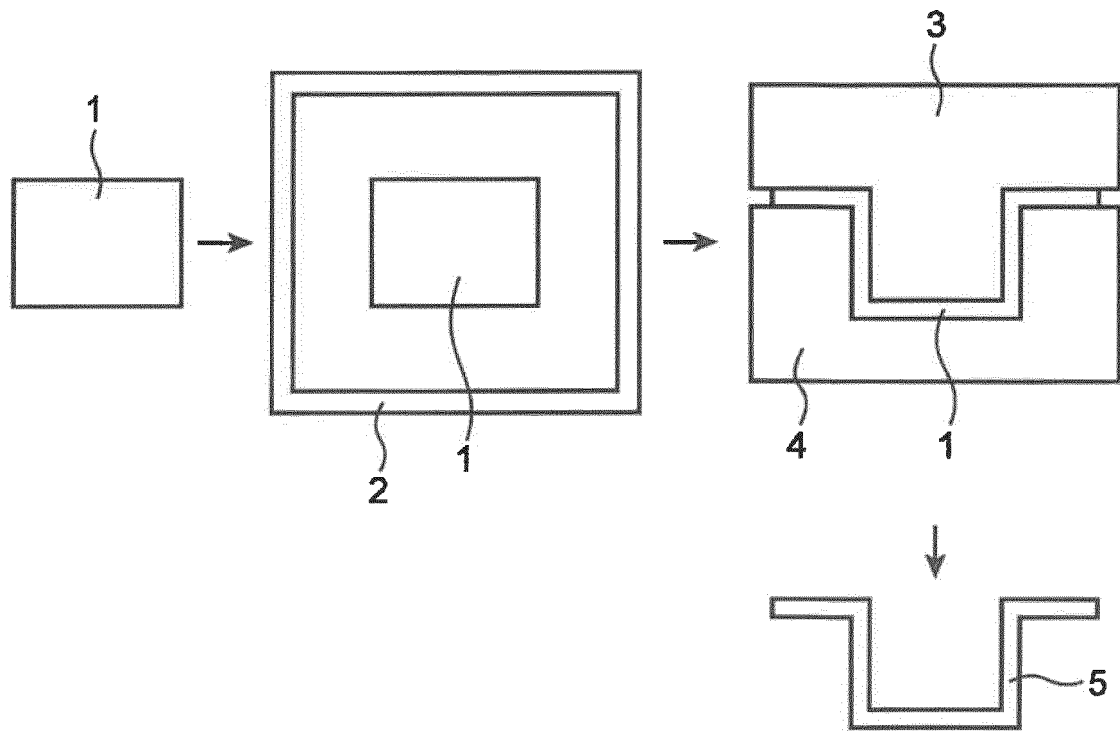


FIG. 3

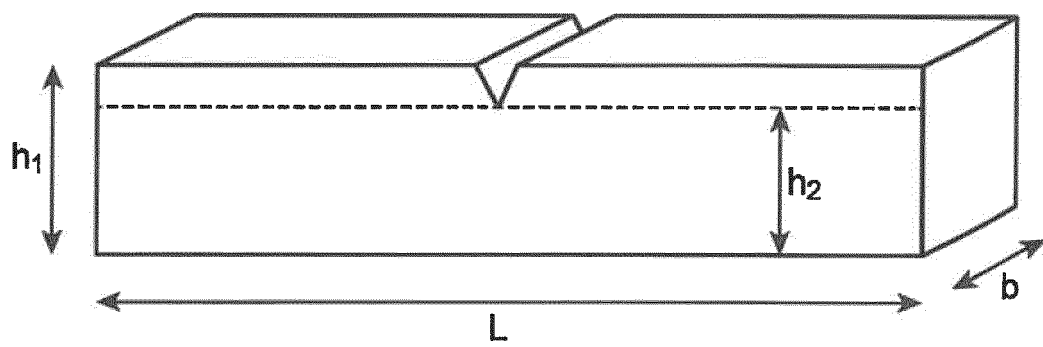
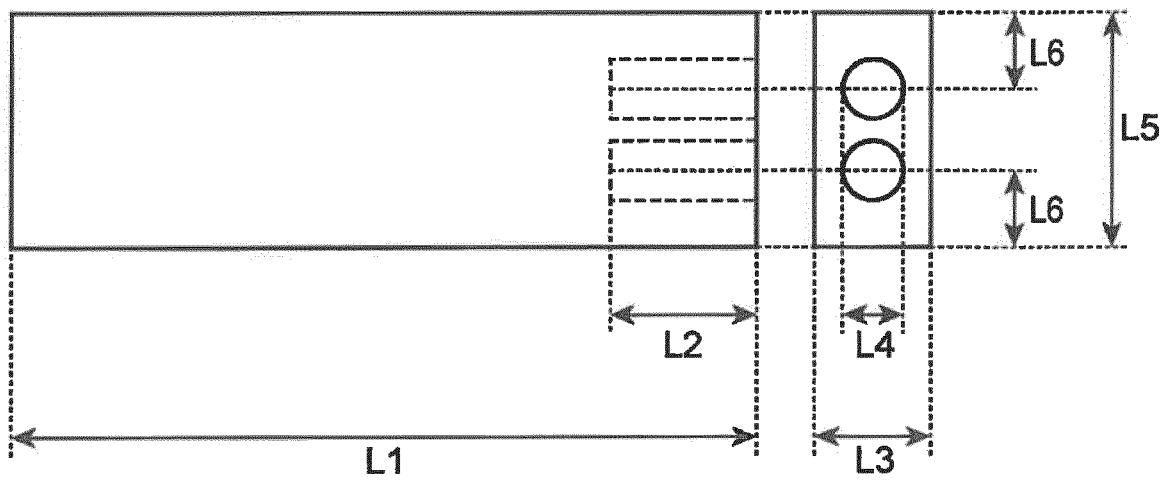


FIG. 4



INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2019/011606

A. CLASSIFICATION OF SUBJECT MATTER

Int.Cl. C22C38/00(2006.01)i, C22C38/32(2006.01)i, C22C38/54(2006.01)i,
C21D1/18(2006.01)n, C21D9/00(2006.01)n, C21D9/46(2006.01)n

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)

Int.Cl. C22C38/00-38/60, C21D1/18, C21D9/00, C21D9/46-9/48

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 1971-2019

Registered utility model specifications of Japan 1996-2019

Published registered utility model applications of Japan 1994-2019

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

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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 2017-155329 A (KOBE STEEL, LTD.) 07 September 2017, claims, paragraphs [0020]-[0034], [0052]-[0080] & US 2019/0017142 A1, claims, paragraphs [0024]-[0051], [0083]-[0169] & WO 2017/149999 A1 & EP 3421631 A1 & CN 108779527 A & KR 10-2018-0117127 A	1-3 3

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

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Date of the actual completion of the international search
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Date of mailing of the international search report
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INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2019/011606

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	JP 2014-156653 A (KOBE STEEL, LTD.) 28 August 2014, claims, paragraphs [0089]-[0101] & US 2015/0354035 A1, claims, paragraphs [0110]-[0134] & WO 2014/112594 A1 & EP 2946848 A1 & KR 10-2015-0095921 A & CN 104936716 A	3
A	JP 2016-3389 A (KOBE STEEL, LTD.) 12 January 2016 & WO 2015/194571 A1	1-3
A	WO 2016/158961 A1 (NIPPON STEEL & SUMITOMO METAL CORPORATION) 06 October 2016 & US 2018/0044754 A1 & EP 3278895 A1 & KR 10-2017-0122823 A & CN 107427889 A	1-3

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

REFERENCES CITED IN THE DESCRIPTION

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Non-patent literature cited in the description

- **KAZUO HIKIDA et al.** Development of TS 1800 MPa Grade Hot Stamping Steel Sheet. *Materia*, 2013, vol. 52 (2), 68-70 **[0007]**
- **KATSUJI NAKASHIMA.** Hardening Technology of Steel by Die Quenching and Application to Body Parts. *CAMP-ISIJ*, 2004, vol. 17, 980-983 **[0008]**