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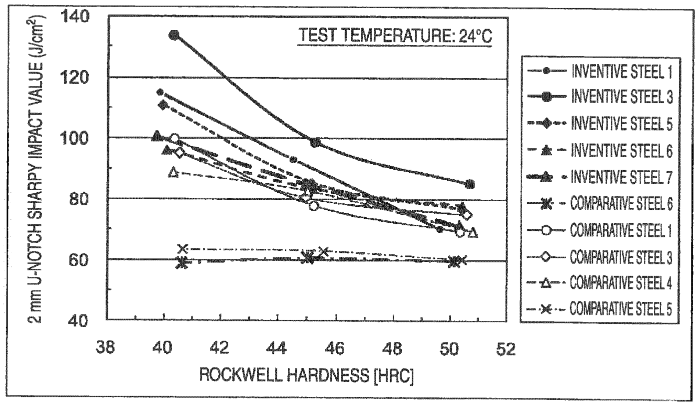
(54) **HOT WORK TOOL STEEL HAVING EXCELLENT TOUGHNESS, AND PROCESS OF PRODUCING SAME**

(57) Provided are a hot work tool steel having improved toughness and a process of producing the hot work tool steel. A hot work tool steel comprising, in mass%, 0.3% or more and less than 0.6% of C, 1.5% or less of Si, 1.5% or less of Mn and 3.0% or more and less than 6.0% of Cr, wherein more than 0.0025% and 0.025% or less of Zn and 0.005% or more of P are contained and the Zn/P ratio is more than 0.5; and a process of producing a hot work tool steel, comprising a first step of preparing a molten steel having a chemical composition of a hot work tool steel containing 0.005 mass% or more of P, a second step of adding Zn to the molten steel having the chemical composition of the hot work tool steel, and a third step of casting the Zn-added molten steel to produce a steel ingot, wherein the second step is a step of adding Zn in such a manner that more than 0.0025 mass% and 0.025 mass% or less of Zn and 0.005 mass% or more of P can be contained in the chemical composition of the steel ingot after the casting in the third step and the hot work tool steel can have a Zn/P ratio of more than 0.5.

FIG.1



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Description

TECHNICAL FIELD

[0001] The present invention relates to a hot work tool steel having improved toughness, which is optimally used for various kinds of hot work tools such as stamping dies, forging dies, die-casting molds and extrusion tools, and a process of producing the same.

BACKGROUND ART

[0002] A hot work tool needs to have both strength and toughness so as to be able to withstand thermal fatigue and impact since it is used while being in contact with a high-temperature workpiece and/or a hard workpiece. Therefore, alloy tool steels of the SKD61 system, for example, which is a JIS steel grade have been conventionally used as a steel grade for use in the field of hot work tools (hereafter, referred to as a hot work tool steel). So, there is proposed a technique for improving the toughness of a hot work tool steel by reviewing the added amounts of principal elements constituting the hot work tool steel, and further restraining and controlling various kinds of impurities such as As, Bi, Sn, Zn, and Sb (see Patent Literature 1). However, adjusting various kinds of impurity elements respectively within a specified range may lead to increase in production cost.

[0003] In contrast to this, the present inventors have conducted diligent studies on elements, which have not been positively used as an alloying element in the field of steel materials, instead of expensive and special elements, and consequently found that toughness can be significantly improved by adding Zn, which conventionally has been treated as an impurity, in a predetermined content range (see Patent Literature 2). That is, the hot work tool steel contains, in mass%, C: 0.3% to less than 0.55%, Si: not more than 1.5%, Mn: not more than 1.5%, and Cr: 3.00 to 5.65%, wherein the hot work tool steel contains Zn: 0.001 to 0.015%.

CITATION LIST

PATENT LITERATURE

[0004]

Patent Literature 1: JP-A-2003-155540
Patent Literature 2: JP-A-2007-224418

SUMMARY OF INVENTION

TECHNICAL PROBLEM

[0005] The technique of adding Zn proposed in Patent Literature 2 is effective as a novel method for improving the toughness of a hot work tool steel. Further, utilizing the method of Patent Literature 2 allows scraps of Zn-plated steel to be used as a recycling raw material, which is also suitable for reducing an environmental load. While focusing on the toughness improving effect by positive addition of Zn, the present inventors have studied on the possibility to compensate for the deterioration of toughness due to other impurity elements. If the permissible amount of those impurity elements can be appropriately increased, it becomes possible to reduce the amount of energy usage required for removing impurities while increasing the usage rate of low level scraps with a high impurity content, the discharge amount of which is expected to increase in the future, thereby further reducing a load on the environment in the production process of hot work tool steels.

[0006] It is an object of the present invention to provide a hot work tool steel having excellent toughness and capable of reducing an environmental load, and a method for producing the same.

SOLUTION TO PROBLEM

[0007] The present inventors have investigated the effects of impurity elements contained in hot work tool steels on the toughness thereof and the environment. Consequently, they have found that in particular P (phosphorus) is the element that significantly reduces the toughness of the hot work tool steel, and also the element that takes a large amount of energy to be removed and, for those reasons, hinders promotion of usage of low grade scraps to impose a large load on the environment. Accordingly, to reduce the environmental load, the present inventors have studied a method of maintaining sufficient toughness even when the permissible amount of P is increased. Consequently, they have determined that deterioration of toughness due to increase in P content can be ceased by adding an appropriate amount of Zn with respect to the P content. Then, the present inventors have arrived at the present invention by making clear the quantitative relationship between P and Zn in which the supplemental effect of toughness can be sufficiently utilized, and a method of adjusting the chemical components suitable for achieving the quantitative relationship.

[0008] That is, the present invention is a hot work tool steel having excellent toughness, including, in mass%, C: 0.3% to less than 0.6%, Si: not more than 1.5%, Mn: not more than 1.5%, and Cr: 3.0 to less than 6.0%, characterized in that Zn is more than 0.0025 to 0.025% and P is not less than 0.005%, and Zn/P is more than 0.5. Preferably, P is not less than 0.01%. Moreover, as desired, Mo and W may be included singly or in combination, wherein an amount of (Mo + 1/2W) is not more than 3.5%, or V: not more than 1.5% may be further included.

[0009] Specifically, the present invention is a hot work tool steel containing: C: 0.3 to less than 0.6%, Si: not more than 1.5%, Mn: not more than 1.5%, Ni: not more than 1.5% (including 0%), Cr: 3.0 to less than 6.0%, Mo and W singly or in combination wherein an amount of (Mo + 1/2W) is not more than 3.5%, V: not more than 1.5%, Nb: not more than 0.3% (including 0%), Co: not more than 5.0% (including 0%), Zn: more than 0.0025 to 0.025%, P: not less than 0.005%, wherein Zn/P is more than 0.5, and the balance is composed of Fe and inevitable impurities. Preferably, P is not less than 0.01 %.

[0010] Moreover, the present invention is a process of producing a hot work tool steel having excellent toughness, including: a first step of obtaining molten steel having a chemical composition of the hot work tool steel including: not less than 0.005 mass% of P; a second step of adding Zn to the molten steel having the chemical composition of the hot work tool steel; and a third step of casting the molten steel to which Zn is added to obtain a steel ingot, characterized in that Zn is added in the second step such that the chemical composition of the steel ingot after casting in the third step becomes the hot work tool steel including Zn: more than 0.0025 to 0.025 mass% and P: not less than 0.005 mass%, with Zn/P being more than 0.5. Preferably, the chemical composition of the molten steel obtained in the first step includes, in mass%, P: not less than 0.01 %, and the chemical composition of the steel ingot after the casting in the third step includes, in mass%, P: not less than 0.01 %. Moreover, the chemical composition of the steel ingot preferably is the hot work tool steel including, in mass%, C: 0.3 to less than 0.6%, Si: not more than 1.5%, Mn: not more than 1.5%, and Cr: 3.0 to less than 6.0%. Moreover, as desired, Mo and W may be included singly or in combination wherein an amount of (Mo + 1/2W) is not more than 3.5%, or V: not more than 1.5% may be further included.

[0011] The chemical composition of the steel ingot after the casting in the third step is most typically a hot work tool steel including, in mass%, C: 0.3 to less than 0.6%, Si: not more than 1.5%, Mn: not more than 1.5%, Ni: not more than 1.5% (including 0%), Cr: 3.0 to less than 6.0%, Mo and W singly or in combination, with an amount of (Mo + 1/2W): not more than 3.5%, V: not more than 1.5%, Nb: not more than 0.3% (including 0%), Co: not more than 5.0% (including 0%), Zn: more than 0.0025 to 0.025%, P: not less than 0.005%, with Zn/P being more than 0.5, and the balance being composed of Fe and inevitable impurities. Preferably, P is not less than 0.01 %.

ADVANTAGEOUS EFFECTS OF INVENTION

[0012] According to the present invention, since sufficient toughness of a hot work tool steel can be maintained even without controlling P (phosphorus) included therein to be at a very low value, it is possible to save energy consumption for lowering a P content, thereby reducing a load on the environment. Further, the amount of Zn to maintain sufficient toughness can be precisely adjusted by the adding method of the present invention. As so far described, the present invention can dramatically improve the toughness of hot work tool steels, and thus provides an effective technique for practically implementing hot work tool steels which are applicable to various uses and environments.

BRIEF DESCRIPTION OF DRAWINGS

[0013]

[Fig. 1] Fig. 1 is a diagram in Example 1 in which 2 mm U-notch Sharpy impact values at a room temperature of steels of the invention and comparative steels, which are thermally refined to be various degrees of hardness, are plotted with respect to the hardness of the specimens.

[Fig. 2] Fig. 2 is a diagram in Example 1 in which 2 mm V-notch Sharpy impact values between a room temperature and 400°C of steels of the invention and comparative steels, which are thermally refined to have hardness of 45 HRC, are plotted with respect to the test temperature.

[Fig. 3] Fig. 3 is a diagram in Example 2 in which 2 mm U-notch Sharpy impact values at a room temperature of a steel of the invention and a comparative steel, which are thermally refined to be various degrees of hardness, are plotted with respect to the hardness of the specimens.

[Fig. 4] Fig. 4 is a diagram in Example 2 in which 2 mm V-notch Sharpy impact values between a room temperature and 400°C of a steel of the invention and a comparative steel, which are thermally refined to have hardness of 45

HRC, are plotted with respect to the test temperature.

DESCRIPTION OF EMBODIMENTS

[0014] A major feature of the present invention is that Zn which has conventionally been treated as an impurity is positively added to improve the toughness of a hot work tool steel. That is, the relationship between P, which is an element that significantly reduces toughness, and the adding amount of Zn of the present invention is made clear so that the content of P is permitted within a certain limit. That is, the present inventors have found that utilizing Zn as an alloying element for a hot work tool steel can exhibit the effect of improving toughness, even if the content of P have increased. Thus, since the content of P, which conventionally needed to be reduced to a very low level, can be permitted up to an increased level, the use amount of expensive low-P scraps can be reduced when selecting raw materials, which is suitable for recycling of scraps. Further, the energy and time needed for removing P in the refining process can be reduced. Hereafter, the reasons for limiting the chemical components of a hot work tool steel to be produced by the present invention will be described (mass% will be simply denoted as "%").

- Zn: more than 0.0025 to 0.025%

[0015] Zn is the most important additive element for the present invention, and its addition remarkably improves the toughness of steel. This effect can be sufficiently achieved by adding an amount of more than 0.0025%. A preferable adding amount is not less than 0.003%. On the other hand, even if a larger amount of Zn is added, its effect will be saturated. Further, if extreme segregation occurs in grain boundaries due to the excessive addition, it may rather be a factor to cause deterioration of toughness. Moreover, since the adding technique thereof will become complicated, the upper limit of Zn is set to 0.025%. It is preferably not more than 0.020%, and more preferably not more than 0.015%.

- P: not less than 0.005%

[0016] P (phosphorous) is an element that segregates in original austenite grain boundaries during a heat treatment such as tempering, thereby embrittling the grain boundaries. Therefore, to improve the toughness of a hot work tool steel, P is an impurity element which has been controlled generally to be as low as possible. However, according to the present invention, it is possible to compensate for the deterioration amount of toughness due to P by making full use of the above-described toughness improvement effect by Zn addition. Thus, a remarkable effect of Zn addition, which is required for the toughness improvement, can be achieved by adjusting the amount of Zn addition with respect to the P content to be described below. As a result of this, a hot work tool steel of the present invention can permit a P content of not less than 0.005%. Sufficient toughness can be maintained even when the P content is preferably not less than 0.01 %, or more preferably not less than 0.02%.

- Zn/P: more than 0.5

[0017] In a hot work tool steel of the present invention, it is necessary to ensure an enough amount of Zn addition to allow sufficient toughness to be maintained even when not less than 0.005% of P is included. For that purpose, the adjustment of the amount of Zn addition with respect to the P content is needed. To be specific, sufficient toughness can be ensured by maintaining the value of Zn/P to be more than 0.5. Preferably, Zn/P is more than 0.55. It is noted that a Zn/P value more than 0.55 is also a preferable condition even when not less than 0.01 % of P, and further not less than 0.02% of P is included.

[0018] To obtain a hot work tool steel satisfying the above-described relationship between P and Zn by a melting and casting process, there is a method of component adjustment suitable therefor. That is, if the chemical composition of molten steel at the time of casting is adjusted so as to include Zn as described above by various methods, a steel ingot of a hot work tool steel according to the present invention can be obtained by just casting the molten steel. However, metallic Zn is a volatile element having a low melting point, and is removed from the molten steel with passage of time. Therefore, for the amount of Zn to be maintained in the molten steel at the time of casting, it is effective to set a larger amount to the amount of Zn at the time of addition to the molten steel by taking account of the above-described amount of removal. However, for controlling the amount of Zn in the molten steel to adjust it at the time of casting to be an appropriate value for the present invention, an adding method which just takes into consideration the above-described amount of removal is poor in reproducibility and therefore it is difficult to achieve the appropriate value. Accordingly, in the present invention, Zn is added to the molten steel at a timing when the P content is fixed by adjusting the chemical composition of the molten steel to that of the hot work tool steel in advance, not by adjusting Zn at the same timing as for other additive elements, thereby making it possible to reduce the passage of time to subsequent casting and to suppress the variation of Zn/P ratio due to the evaporation of Zn, and so on.

[0019] That is, to be specific, the present invention includes a first step of obtaining a molten steel having a chemical composition of a hot work tool steel including not less than 0.005 mass% of P; a second step of adding Zn to the molten steel having the chemical composition of the hot work tool steel; and a third step of casting the above-described molten steel to which Zn has been added to obtain a steel ingot. In the method for producing a hot work tool steel, Zn is added in the second step such that the chemical composition of the steel ingot after casting in the third step becomes the hot work tool steel including Zn: more than 0.0025 to 0.025 mass% and P: not less than 0.005 mass%, with Zn/P being more than 0.5. The content of P included in the steel ingot after casting in the above-described third step is preferably not less than 0.01 mass%, and more preferably not less than 0.02 mass%. Each of the steps will be described below.

- First Step: a step of obtaining molten steel having a chemical composition of a hot work tool steel including not less than 0.005 mass% of P.

[0020] By adjusting the chemical composition of the molten steel to be matched with that of the hot work tool steel in advance, the second step to be described later can be fully specialized to the adjustment of Zn content. Since it is possible to quickly change over to the casting in the third step to be described later after the addition of a predetermined amount of Zn, the Zn content of the steel ingot after casting can be appropriately adjusted with ease. It is noted that "to prepare molten steel having a chemical composition of a hot work tool steel" in the first step of the present invention means that a state of molten steel of a hot work tool steel which is adjusted to have various chemical compositions is obtained before the second step to be described later. The chemical composition at this time is preferably adjusted to the chemical composition of the target steel ingot. Further, at this time, if the chemical composition varies before and after the Zn addition depending on the kind (chemical composition) of the Zn source to be used for the next Zn addition, it is preferable to take this variation amount into consideration. Therefore, the first step is not limited to a treatment such as alloy addition to molten steel, and may be the work for preparing raw materials before melting for example. After melting, the molten steel may be subjected to various refining processing for removing inclusions and impurities. It is noted that the P content included in the molten steel obtained in the first step is preferably not less than 0.01 mass%, and more preferably not less than 0.02 mass%.

- Second Step: a step of adding Zn to the molten steel of the hot work tool steel according to the first step.

[0021] In the present invention, it is important, as described above, to control the second step of adding Zn separately from the above-described first step. If Zn is added to the molten steel which is adjusted to have the chemical composition of a hot work tool steel in advance, it is easy to adjust the Zn content with respect to P, and it is possible to change over to the casting in the third step to be described later. It is noted that the second step of the present invention does not exclude processing for purposes other than for adding Zn. Therefore, at this time, if there is slight difference for any kind of element other than Zn in the chemical composition from that of the targeted steel ingot, an additional fine adjustment may be performed provided that new refining process is not conducted.

- Third Step: a step of casting the molten steel according to the second step to obtain a steel ingot.

[0022] By casting the molten steel, which is subjected to the first and the second steps, to obtain a steel ingot, a hot work tool steel satisfying the chemical composition of the present invention is produced by melting. The casting in the third step of the present invention is not limited to a normal ingot-making process, but may be a continuous casting process and other special ingot-making processes.

[0023] If a large amount of carbide is distributed in the microstructure of steel, the toughness improvement effect by Zn addition of the present invention will be greatly impaired thereby and the steel is weakened. That is, the above-described toughness improvement effect is fully exhibited in the case of a hot work tool steel with little carbide compared to a cold work tool steel with a large amount of carbide distributed in the microstructure thereof. Therefore, the object of the present invention is limited to hot work tool steels. A hot work tool steel refers to a steel having a chemical composition specified by, for example, JIS-G-4404, etc. Besides standard steel grades of JIS etc., hot work tool steels which have conventionally been proposed can be applied. Any kind of element other than those specified in the above-described hot work tool steel can be added as desired. Shown below are preferable chemical compositions of a hot work tool steel to be produced by the present invention. The reasons for quantitative limits will be described.

- C: 0.3 to less than 0.6%

[0024] C (carbon) is an element that is partially solid-solved into the matrix, thereby adding strength thereto, and partially forms carbide, thereby improving the wear resistance and seizure resistance. Moreover, when C, which is an interstitial atom in a solid solution, is added together with a substitutional atom having a large affinity with C, such as

Cr, it is expected to work as the drag resistance for solute atoms due to an I(interstitial)-S(substitutional) interaction, thereby enhancing the strength of steel. However, excessive addition will cause deterioration of toughness and hot strength. Therefore, C is preferably 0.3 to less than 0.6%, and more preferably less than 0.55%.

- Si: not more than 1.5%

[0025] Si (silicon) is a deoxidizer at the time of steel making, and is an element that improves the machinability of the steel material. To achieve these effects, although addition may be less than 0.2%, addition of not less than 0.2% is more preferable. However, since excessive addition will cause the generation of ferrite, a preferable amount of addition is not more than 1.5%.

- Mn: not more than 1.5%

[0026] Mn (manganese) has effects of increasing hardenability, suppressing the generation of ferrite, and obtaining an appropriate quenching and tempering hardness. Moreover, Mn has a large effect on the improvement of machinability by being present as MnS which is a non-metallic inclusion. Although addition may be less than 0.1 % to achieve these effects, addition of not less than 0.1 % is preferable. However, since excessive addition will increase the viscosity of the matrix, thereby deteriorating machinability, a preferable amount of addition is not more than 1.5%.

- Cr: 3.0 to less than 6.0%

[0027] Cr (chromium) is an element that increases hardenability, forms carbide, and has effects of strengthening the matrix and improving wear resistance. Cr also contributes to the improvements of the resistance to temper softening, and of high-temperature strength. However, excessive addition will cause deterioration of hardenability and high-temperature strength. Therefore, the amount of addition is preferably 3.0 to less than 6.0%, and is more preferably not more than 5.65%.

- Mo and W singly or in combination, with an amount of (Mo + 1/2W): not more than 3.5%

[0028] Mo and W can be added singly or in combination to add strength by causing fine carbides to precipitate or aggregate by tempering, thereby improving the resistance to softening. The amount of addition in this case can be specified together in terms of a Mo equivalent, (Mo + 1/2W), since W has an atomic weight approximately twice of that of Mo (of course, only either one of them may be added or both may be added together). To achieve the above-described effects, although the amount of addition may be less than 1.0% in terms of the value of (Mo + 1/2W), the addition of not less than 1.0% is preferable. However, since excessive addition will cause deterioration of machinability and toughness, a preferable amount of addition is not more than 3.5% in terms of the value of (Mo + 1/2W).

- V: not more than 1.5%

[0029] V (vanadium) forms carbides and thereby has effects of strengthening the matrix and improving the wear resistance. Moreover, it increases the resistance to temper softening and suppresses the coarsening of crystal grains, thereby contributing to the improvement of toughness. Although the amount of addition may be less than 0.5% to achieve these effects, the addition of not less than 0.5% is preferable. However, since excessive addition will cause deterioration of machinability and toughness, a preferable amount of addition is not more than 1.5%.

- Ni: not more than 1.5%

[0030] Ni (nickel) is an element that suppresses the generation of ferrite. Moreover, Ni is an effective element that adds, along with C, Cr, Mn, Mo, W and the like, excellent hardenability to a hot work tool steel, and allows the formation of a microstructure predominantly made up of martensite even when the cooling rate at the time of quenching is slow, thus preventing deterioration of toughness. Further, since Ni improves intrinsic toughness of the matrix, Ni is added as needed in the present invention. However, excessive addition will increase the viscosity of the matrix, thereby deteriorating machinability. Therefore, even when it is added, an amount of not more than 1.5% is preferable. Also, when it is added, a preferable amount is not less than 0.1 %.

- Nb: not more than 0.3%

[0031] Nb (niobium) forms carbides and has effects of strengthening the matrix, and improving wear resistance.

Moreover, since Nb increases the resistance to temper softening, and suppresses the coarsening of crystal grains thereby contributing to the improvement of toughness, Nb is added as needed in the present invention. However, excessive addition will cause deterioration of machinability and toughness. Therefore, even when it is added, a preferable amount is not more than 0.3%. When it is added, a preferable amount is not less than 0.05%.

- Co: not more than 5.0%

[0032] Co (cobalt) forms a very fine protective oxide film having good adhesiveness on a surface of a hot work tool steel according to the present invention when using the hot work tool as a tool at an increased temperature. The oxide film prevents metallic contact with a counterpart material, thereby suppressing temperature rise at the surface of the tool, and providing excellent wear resistance. Therefore, Co is added as needed in the present invention. However, excessive addition will cause deterioration of toughness. Therefore, even when it is added, an amount of not more than 5.0% is preferable. Also, when it is added, a preferable amount is not less than 0.3%.

[0033] Major elements which may remain in steel as an inevitable impurity are S, Cu, Al, Ca, Mb, O (oxygen), N (nitrogen), and so on. To effectively achieve the effects of Zn addition of the present invention, the contents of these elements are preferably as low as possible. However, on the other hand, to effectively achieve additional actions and effects such as morphology control of inclusions, improvements of other mechanical properties and productivity, they may be included and/or added in a slight amount. In this case, the ranges of S ≤ 0.01%, Cu ≤ 0.25%, Al ≤ 0.025%, Ca ≤ 0.01%, Mg ≤ 0.01%, O ≤ 0.01%, and N ≤ 0.03% are fully permissible, and indicate the upper limits of preferable specifications of the present invention.

[0034] As one example of sufficiently exhibiting the toughness improvement effect by Zn addition, a hot work tool steel relating to the present invention is preferably subjected to a homogenizing heat treatment, for example, during processing of a steel ingot after casting to finish it into a steel product. Further, the quenching and tempering hardness is preferably not more than 50 HRC, and is more preferably not more than 48 HRC.

EXAMPLE 1

[0035] First, molten steel adjusted to have a chemical composition of a hot work tool steel including not less than 0.005 mass% of P was maintained by a vacuum induction melting furnace. The chemical composition at this time was adjusted to be the chemical composition of a target steel ingot after subsequent Zn addition (that is, charging of a Zn source). Thereafter, Zn was added to the molten steel by using a Zn plated steel sheet as the Zn source, and the molten steel was cast to fabricate a steel ingot weighing 7 to 10 kg. Table 1 shows the chemical compositions of the steel ingots after casting. The Zn contents were measured by an X-ray fluorescence analysis. Inventive steels were obtained by adding Zn to have a chemical composition of a generally used hot work tool steel of JIS-SKD61 (specified P: not more than 0.030%) such that the Zn/P ratio of the present invention was satisfied, thereby permitting an increased amount of P content. It is noted that in all the steel ingots, none of S, Cu, Al, Ca, Mg, O, and N was added (although, the case in which Al was added as a deoxidizer in the melting process was included), wherein S ≤ 0.01 %, Cu ≤ 0.25%, Al ≤ 0.025%, Ca ≤ 0.01 %, Mg ≤ 0.01 %, O ≤ 0.01%, and N ≤ 0.03%. Thus, it was possible to appropriately adjust the contents of P and Zn of inventive steels, to which Zn was added before casting, into the predetermined relationship. In contrast to this, when Zn was added in an early stage of the above-described vacuum induction melting, Zn was vaporized and thus it was not possible to maintain the predetermined amount of Zn in the molten steel before casting.

[0036] On the other hand, Comparative steels 1 to 6 shown in Table 1 were also prepared for explaining the effects of Zn addition of the present invention. In these comparative steels, Zn was not added (excepting Comparative Steel 6) and only the P content of SKD61 was increased. Also, none of S, Cu, Al, Ca, Mg, O, and N was added (although, the case in which Al was added as a deoxidizer in the melting process was included), with S ≤ 0.01%, Cu ≤ 0.25%, Al ≤ 0.025%, Ca ≤ 0.01%, Mg ≤ 0.01%, O ≤ 0.01%, and N ≤ 0.03%.

[Table 1]

(Mass %)

Specimen	C	Si	Mn	P	Ni*1	Cr	Mo
Inventive steel 1	0.38	1.01	0.46	0.006	0.01	5.21	1.26
Inventive steel 2	0.38	1.00	0.45	0.006	0.01	5.14	1.27
Inventive steel 3	0.38	1.04	0.45	0.007	0.02	5.11	1.21
Inventive steel 4	0.38	0.99	0.45	0.006	0.01	5.05	1.26
Inventive steel 5	0.38	1.02	0.45	0.016	0.02	5.07	1.21
Inventive steel 6	0.37	0.98	0.45	0.023	0.01	5.04	1.17
Inventive steel 7	0.39	1.01	0.46	0.019	0.01	5.13	1.23
Comparative steel 1	0.38	1.03	0.44	0.007	0.01	5.19	1.24
Comparative steel 2	0.38	1.03	0.43	0.008	0.01	5.13	1.25
Comparative steel 3	0.38	1.02	0.44	0.016	0.01	5.25	1.23
Comparative steel 4	0.38	1.03	0.43	0.021	0.01	5.20	1.23
Comparative steel 5	0.39	1.02	0.43	0.039	<0.01	5.14	1.24
Comparative steel 6	0.38	0.97	0.43	0.039	0.01	5.21	1.28

Specimen	W*1	V	Zn	Nb*1	Co*1	Fe*2	Zn/P
Inventive steel 1	<0.01	0.76	0.005	<0.01	<0.01	Balance	0.83
Inventive steel 2	<0.01	0.77	0.004	<0.01	<0.01	Balance	0.67
Inventive steel 3	<0.01	0.82	0.011	<0.01	<0.01	Balance	1.57
Inventive steel 4	<0.01	0.77	0.008	<0.01	<0.01	Balance	1.33
Inventive steel 5	<0.01	0.80	0.012	<0.01	<0.01	Balance	0.75
Inventive steel 6	<0.01	0.79	0.013	<0.01	<0.01	Balance	0.57
Inventive steel 7	<0.01	0.82	0.019	<0.01	<0.01	Balance	1.00
Comparative steel 1	<0.01	0.82	<0.001	<0.01	<0.01	Balance	<0.5
Comparative steel 2	<0.01	0.82	<0.001	<0.01	<0.01	Balance	<0.5
Comparative steel 3	<0.01	0.82	<0.001	<0.01	<0.01	Balance	<0.5
Comparative steel 4	<0.01	0.81	<0.001	<0.01	<0.01	Balance	<0.5
Comparative steel 5	<0.01	0.82	<0.001	<0.01	<0.01	Balance	<0.5
Comparative steel 6	<0.01	0.81	0.010	<0.01	<0.01	Balance	0.26

*1 Not added
*2 Including impurities

[0037] After being subjected to the homogenizing heat treatment at 1250°C for 5 hours, these steel ingots were hot forged at 1150°C to fabricate a steel product of 20 mm thickness, 60 mm width, and about 500 to 800 mm length. Then, after being annealed at 860°C, the steel product was machined into a size of Sharpy impact test specimen to be used for the evaluation described below, and was oil-quenched from 1030°C and tempered at various temperatures to obtain specimens for evaluating toughness at respective thermally refined hardnesses.

[Test 1]

[0038] Fig. 1 shows the results of 2 mm U-notch Sharpy impact test of Inventive steels 1, 3, 5 to 7, and Comparative steels 1, 3 to 6 at their respective hardnesses. The Sharpy test specimen was directed in the T-L direction according to ASTM E399-90. Inventive steels 1, 3, 5 to 7 in which Zn was added so as to satisfy the Zn/P ratio of the present invention exhibited more excellent Sharpy impact values than Comparative steels 1, 3, 4 in which no Zn was added, in the combinations of: Inventive steels 1, 3 and Comparative steel 1; Inventive steels 5 and Comparative steel 3; and Inventive steels 6, 7 and Comparative steel 4, where the respective steels included the same level of P in each combination. Further, even though having included P at a high density of more than 0.02%, Inventive steel 6 exhibited toughness of the same level as that of Comparative steel 1, which contained less than 0.01% of P, owing to the addition of Zn. Comparative steel 6, which was obtained by adding Zn to Comparative steel 5 including the same level of P, did not satisfy Zn/P of the present invention, and exhibited no improvement in toughness.

[Test 2]

[0039] Fig. 2 shows the results of 2 mm V-notch Sharpy impact test of Inventive steels 2, 4 to 7 and Comparative steels 2 to 6 at temperatures from room temperature to 400°C, wherein the steels have a hardness of 45 HRC by thermally refining. The Sharpy test specimen was directed in the T-L direction according to ASTM E399-90. Inventive steels 2, 4 to 7 in which Zn was added so as to satisfy the Zn/P ratio of the present invention exhibited more excellent Sharpy impact values than those of Comparative steels 2 to 4 which included the same level of P, at any test temperature, in the respective combinations of: Inventive steels 2, 4 and Comparative steel 2; Inventive steels 5 and Comparative steel 3; and Inventive steels 6, 7 and Comparative steel 4, where the respective steels included the same level of P in each combination. Further, even though having included P at a higher density of more than 0.02%, Inventive steel 6, which satisfied the Zn/P ratio of the present invention as the result of addition of Zn, maintained the same level of toughness as that of Comparative steel 2 which contained less than 0.01 % of P.

EXAMPLE 2

[0040] Steel ingots having chemical compositions of Table 2 were fabricated in the same manner as described in Example 1. Inventive steel A was prepared by adding Zn to the chemical composition of a hot work tool steel such that Zn/P ratio of the present invention was satisfied. Comparative steel B had the same chemical composition as that of Inventive steel A excepting that no Zn was added. It is noted that in both the steel ingots, none of S, Cu, Al, Ca, Mg, O, and N was added (although, Al was added as a deoxidizer in the melting process), wherein S $\leq$ 0.01%, Cu $\leq$ 0.25%, Al $\leq$ 0.025%, Ca $\leq$ 0.01%, Mg $\leq$ 0.01%, O $\leq$ 0.01%, and N $\leq$ 0.03%.

[Table 2]

(Mass%)

Speciment	C	Si	Mn	P	Ni	Cr	Mo
Inventive steel A	0.37	0.28	0.60	0.005	0.60	5.15	1.60
Comparative steel B	0.38	0.30	0.56	0.007	0.59	5.03	1.58

Specimen	W※1	V	Zn	Nb※1	Co※1	Fe※2	Zn/P
Inventive steel A	<0.01	0.65	0.016	<0.01	<0.01	Balance	3.20
Comparative steel B	<0.01	0.65	<0.001	<0.01	<0.01	Balance	<0.5

*1 Not added
*2 Including impurities

[0041] Next, these steel ingots were subjected to hot forging and various heat treatments similar to those in Example 1, to fabricate Sharpy impact test specimens which were thermally refined to have respective hardnesses. Then, Sharpy impact tests 1 and 2, which were conducted in Example 1, were conducted to evaluate the toughness of each specimen.

[Test 1]

[0042] Fig. 3 shows the results of 2 mm U-notch Sharpy impact test of Inventive steel A and Comparative steel B at room temperature at respective degrees of hardness. The Sharpy test specimen was oriented in the T-L direction according to ASTM E399-90. These steels originally had high toughness because Ni was added thereto. Besides, Inventive steel A, to which Zn was added so as to satisfy Zn/P ratio of the present invention, exhibited more excellent Sharpy impact values compared to those of Comparative steel B to which Zn was not added.

[Test 2]

[0043] Fig. 4 shows the results of 2 mm V-notch Sharpy impact test of Inventive steel A and Comparative steel B at temperatures from room temperature to 400°C wherein the steels have a hardness of 45 HRC by thermal refining. The Sharpy test specimen was oriented in the T-L direction according to ASTM E399-90. In both steels originally having high toughness, Inventive steel A, to which Zn was further added so as to satisfy the Zn/P ratio of the present invention, exhibited more excellent Sharpy impact values at any test temperature compared with Comparative steel B to which Zn was not added.

Claims

1. A hot work tool steel having excellent toughness, including, in mass%: 0.3 to less than 0.6% of C; not more than 1.5% of Si; not more than 1.5% of Mn; and 3.0 to less than 6.0% of Cr, **characterized in that** the hot work tool steel further includes: more than 0.0025 to 0.025% of Zn; and not less than 0.005% of P, and **in that** Zn/P is more than 0.5.

2. The hot work tool steel having excellent toughness according to claim 1, **characterized by** including at least one of Mo and W, wherein an amount of (Mo + 1/2W) is not more than 3.5%, in mass%.

3. The hot work tool steel having excellent toughness according to claim 1 or 2, **characterized by** including not more than 1.5% of V, in mass%.

4. The hot work tool steel having excellent toughness according to claim 1, **characterized by** containing, in mass%:

    0.3 to less than 0.6% of C;
    not more than 1.5% of Si;

not more than 1.5% of Mn;
not more than 1.5% (including 0%) ofNi;
3.0 to less than 6.0% of Cr;
at least one of Mo and W, wherein an amount of (Mo + 1/2W) is not more than 3.5%;
not more than 1.5% of V;
not more than 0.3% (including 0%) of Nb;
not more than 5.0% (including 0%) of Co;
more than 0.0025 to 0.025% of Zn;
not less than 0.005% of P, wherein Zn/P is more than 0.5; and
the balance consisting of Fe and inevitable impurities.

5. The hot work tool steel having excellent toughness according to claim 1 or 4, **characterized in that** P is not less than 0.01 %, in mass%.

6. A process of producing a hot work tool steel having excellent toughness, including:

a first step of obtaining molten steel having a chemical composition of a hot work tool steel including not less than 0.005 mass% of P;
a second step of adding Zn to the molten steel having the chemical composition of the hot work tool steel; and
a third step of casting the molten steel to which Zn is added to obtain a steel ingot, **characterized in that**
Zn is added in the second step such that a chemical composition of the ingot after casting in the third step is a hot work tool steel including more than 0.0025 to 0.025 mass% of Zn and not less than 0.005 mass% of P, wherein Zn/P is more than 0.5.

7. The process of producing a hot work tool steel having excellent toughness according to claim 6, **characterized in that** the chemical composition of the steel ingot after casting in the third step is the hot work tool steel including, in mass%: 0.3 to less than 0.6% of C, not more than 1.5% of Si, not more than 1.5% of Mn, and 3.0 to less than 6.0% of Cr.

8. The process of producing a hot work tool steel having excellent toughness according to claim 7, **characterized in that** the chemical composition of the steel ingot after casting in the third step is the hot work tool steel including at least one of Mo and W wherein an amount of (Mo + 1/2W) is not more than 3.5%, in mass%.

9. The process of producing a hot work tool steel having excellent toughness according to claim 7 or 8, **characterized in that** the chemical composition of the steel ingot after casting in the third step is the hot work tool steel including , in mass%, not more than 1.5% of V.

10. The process of producing a hot work tool steel having excellent toughness according to claim 6, **characterized in that** the chemical composition of the steel ingot after casting in the third step is the hot work tool steel containing, in mass%:

0.3 to less than 0.6% of C;
not more than 1.5% of Si;
not more than 1.5% of Mn;
not more than 1.5% (including 0%) ofNi;
3.0 to less than 6.0% of Cr;
at least one of Mo and W, wherein an amount of (Mo + 1/2W) is not more than 3.5%;
not more than 1.5% of V;
not more than 0.3% (including 0%) of Nb;
not more than 5.0% (including 0%) of Co;
more than 0.0025 to 0.025% of Zn;
not less than 0.005% of P, wherein Zn/P is more than 0.5; and
the balance consisting of Fe and inevitable impurities.

11. The process of producing a hot work tool steel having excellent toughness according to claim 6 or 10, **characterized in that** the chemical composition of the molten steel obtained in the first step includes, in mass%, not less than 0.01 % of P, and the chemical composition of the steel ingot after casting in the third step includes, in mass%, not less than 0.01 % of P.

FIG.1

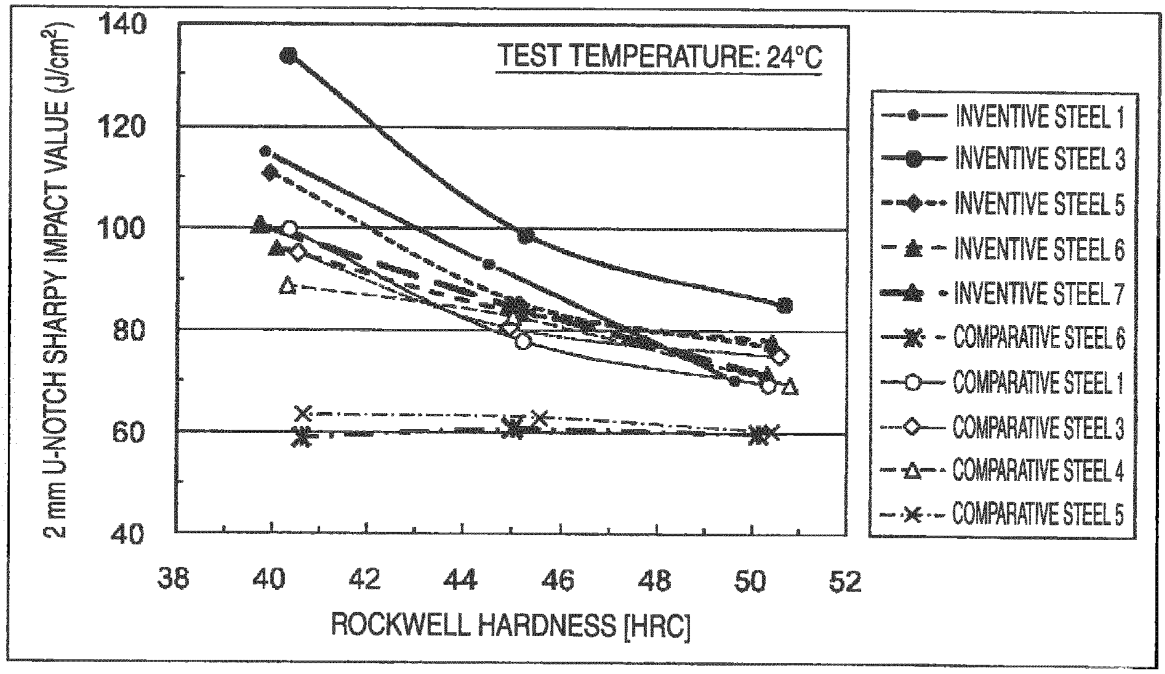

2 mm U-NOTCH SHARPY IMPACT VALUE (J/cm²)
140
120
100
80
60
40
TEST TEMPERATURE: 24°C
38
40
42
44
46
48
50
52
ROCKWELL HARDNESS [HRC]
INVENTIVE STEEL 1
INVENTIVE STEEL 3
INVENTIVE STEEL 5
INVENTIVE STEEL 6
INVENTIVE STEEL 7
COMPARATIVE STEEL 6
COMPARATIVE STEEL 1
COMPARATIVE STEEL 3
COMPARATIVE STEEL 4
COMPARATIVE STEEL 5

FIG.2

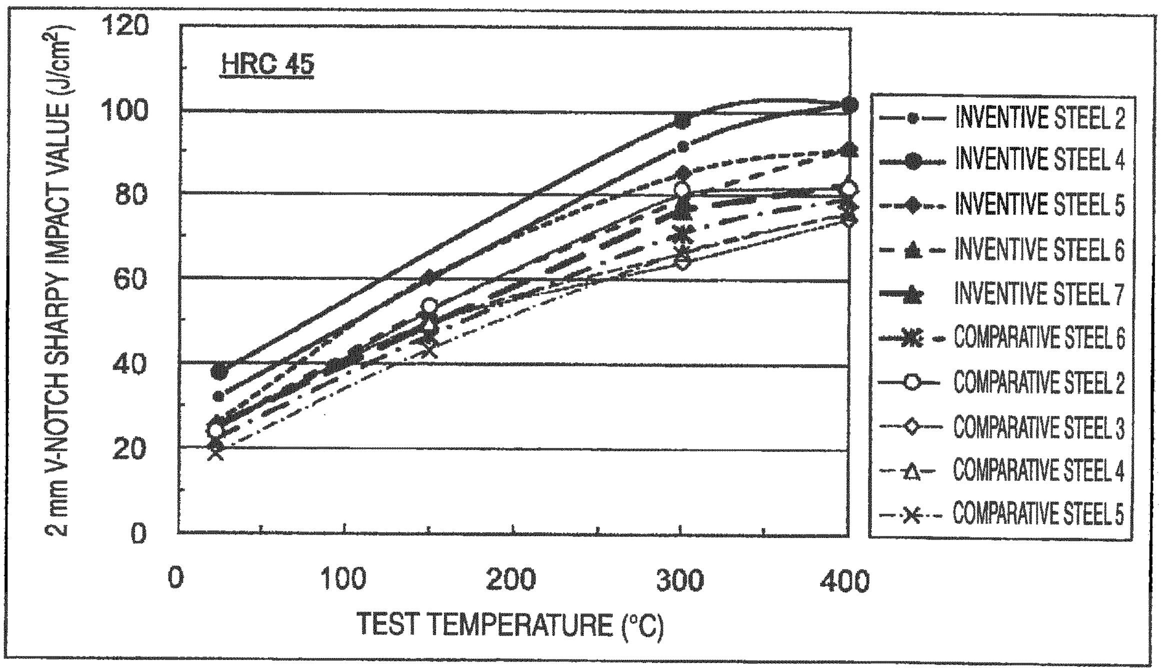

2 mm V-NOTCH SHARPY IMPACT VALUE (J/cm²)
120
100
80
60
40
20
0
HRC 45
0
100
200
300
400
TEST TEMPERATURE (°C)
INVENTIVE STEEL 2
INVENTIVE STEEL 4
INVENTIVE STEEL 5
INVENTIVE STEEL 6
INVENTIVE STEEL 7
COMPARATIVE STEEL 6
COMPARATIVE STEEL 2
COMPARATIVE STEEL 3
COMPARATIVE STEEL 4
COMPARATIVE STEEL 5

FIG.3

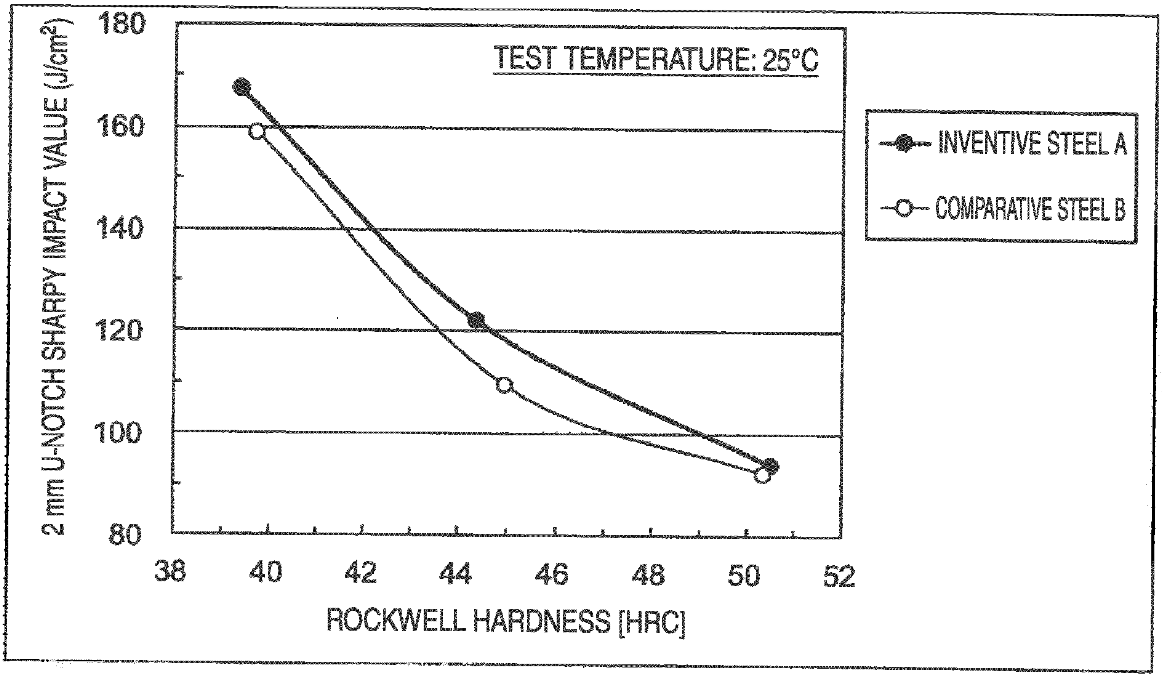
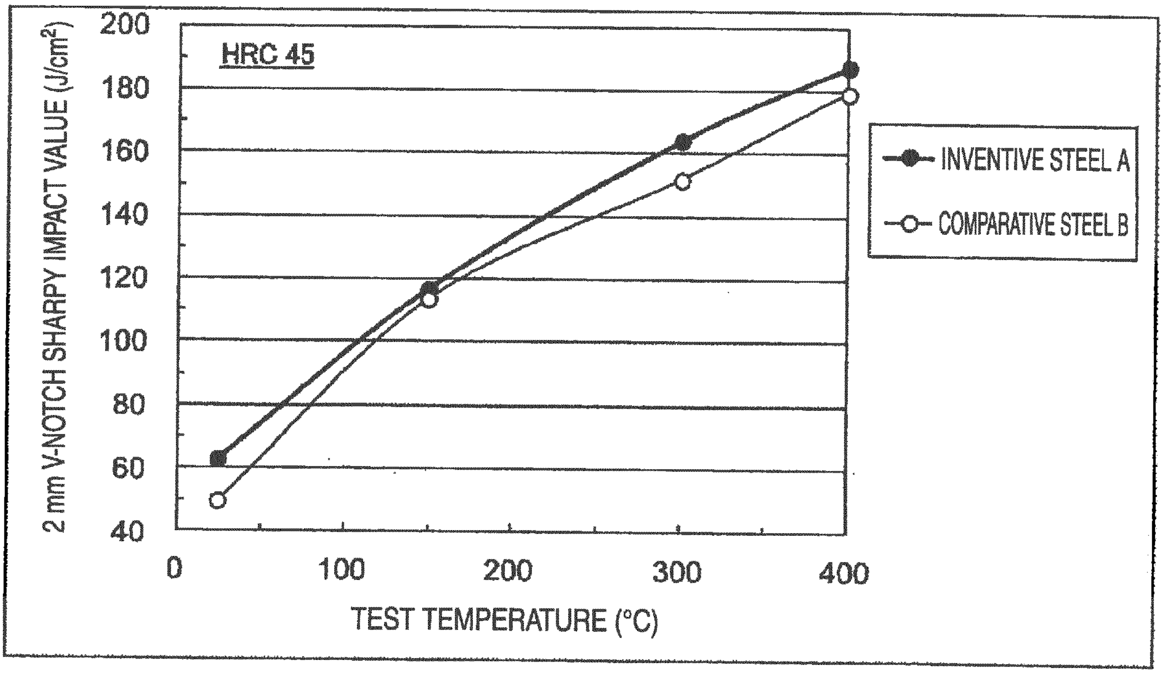

TEST TEMPERATURE: 25°C
2 mm U-NOTCH SHARPY IMPACT VALUE (J/cm2)
180
160
140
120
100
80
38
40
42
44
46
48
50
52
ROCKWELL HARDNESS [HRC]
INVENTIVE STEEL A
COMPARATIVE STEEL B

FIG.4


HRC 45
2 mm V-NOTCH SHARPY IMPACT VALUE (J/cm2)
200
180
160
140
120
100
80
60
40
0
100
200
300
400
TEST TEMPERATURE (°C)
INVENTIVE STEEL A
COMPARATIVE STEEL B

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2012/054868

A. CLASSIFICATION OF SUBJECT MATTER
C22C38/00(2006.01)i, *C22C38/18*(2006.01)i, *C22C38/52*(2006.01)i

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, C22C38/18, C22C38/52

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

Jitsuyo Shinan Koho	1922-1996	Jitsuyo Shinan Toroku Koho	1996-2012
Kokai Jitsuyo Shinan Koho	1971-2012	Toroku Jitsuyo Shinan Koho	1994-2012

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.
A	JP 2007-224418 A (Hitachi Metals, Ltd.), 06 September 2007 (06.09.2007), claims 1 to 6 (Family: none)	1-11
A	JP 2004-18925 A (Nippon Steel Corp.), 22 January 2004 (22.01.2004), claims 1 to 7 & WO 2003/106724 A1 & CN 1659297 A	1-11
A	JP 2004-100027 A (Nippon Steel Corp.), 02 April 2004 (02.04.2004), claims 1 to 5 (Family: none)	1-11

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

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
19 April, 2012 (19.04.12)	01 May, 2012 (01.05.12)

Name and mailing address of the ISA/	Authorized officer
Japanese Patent Office	
Facsimile No.	Telephone No.

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Patent documents cited in the description

- JP 2003155540 A **[0004]**
- JP 2007224418 A **[0004]**