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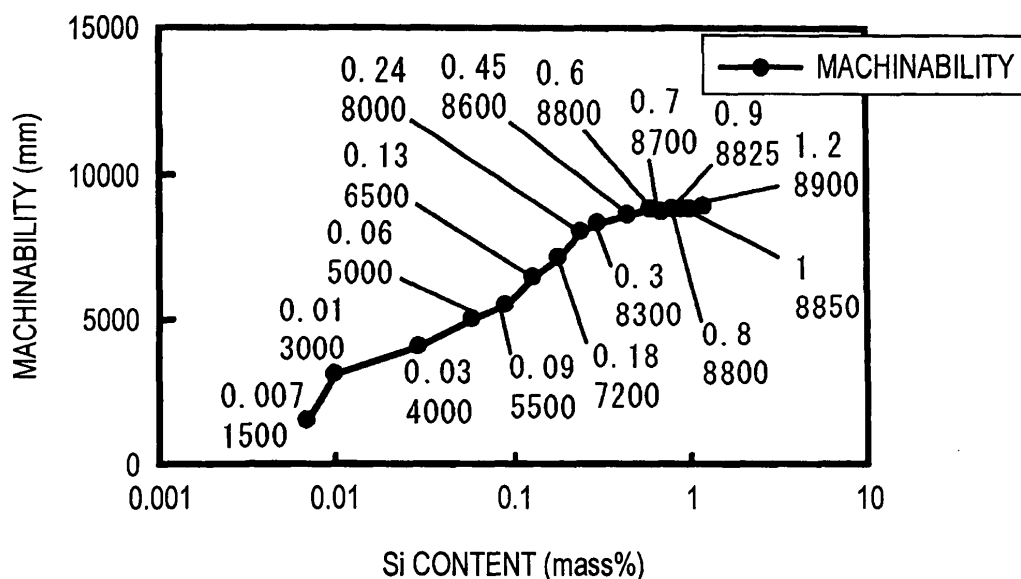
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(54) **Hot work tool steel and steel product using the same**

(57) The present invention provides a hot work tool steel containing: $0.20 \leq C \leq 0.50$ mass%, $0.01 \leq Si \leq 0.25$ mass%, $0.50 < Mn \leq 1.50$ mass%, $5.24 < Cr \leq 9.00$ mass%, $1.24 < Mo < 2.95$ mass%, and $0.30 < V < 0.70$ mass%, with the balance being Fe and unavoidable impurities; and a

steel product using the hot work tool steel. The hot work tool steel of the present invention is assured of machinability industrially allowing for working into a die shape and enhanced in the thermal conductivity and impact value as compared with general-purpose die steel (for example, JIS SKD61).

FIG. 1



Description

FIELD OF THE INVENTION

5 **[0001]** The present invention relates to a hot work tool steel and a steel product using the same. More specifically, the present invention relates to a hot work tool steel assured of machinability industrially allowing for working into a die shape and enhanced in the thermal conductivity and impact value as compared with general-purpose die steel (for example, JIS SKD61), and a steel product using the same.

10 BACKGROUND OF THE INVENTION

[0002] As regards a die material used for die casting, hot forging and warm forging, JIS SKD61 excellent in machinability is being used for general purposes. However, JIS SKD61 has a low thermal conductivity and in turn carries a problem that the die temperature tends to be high and the die life is decreased due to frequent occurrence of soldering or heat checking. Furthermore, with an increase in size of the die, microstructure refinement of JIS SKD61 becomes difficult because of its high transformation temperature of bainitic transformation under the condition of small cooling rate (so called hardenability), and this leads to a significant decrease in toughness. Therefore, JIS SKD61 is disadvantageous in that heat checking is promoted and the die life is further shortened. Under these circumstances, a hot work tool steel superior in the thermal conductivity and impact value to JIS SKD61 is demanded in industry.

20 **[0003]** In this connection, various steels suitable for this kind of application have been proposed. For example, Patent Document 1 discloses a hot work tool steel excellent in transformation behavior (hardenability) and creep property and substitutable for JIS SKD61, which is a steel containing, as essential components, C: from 0.30 to 0.38 wt%, Si: from 0.10 to 0.40 wt%, Mn: from 0.60 to 0.80 wt%, Cr: from 5.40 to 5.70 wt%, Mo: from 1.50 to 1.70 wt%, and V: from 0.70 to 0.85 wt%, with the balance being Fe and unavoidable impurities.

25 **[0004]** Patent Document 2 discloses a die for width sizing of a hot slab, improved in wear resistance and heat crack resistance by introducing a thermal shock factor K, which is a steel containing, in terms of wt%, C: from 0.1 to 0.5%, Si: from 0.1 to 1.5%, Mn: from 0.2 to 1.5%, Ni: 5.0% or less, Cr: from 0.5 to 5.0%, Mo: 1.5% or less, V: 1.0% or less, and Cu: 0.2% or less, with the balance being Fe and impurities.

30 **[0005]** Patent Document 3 discloses a hot work tool steel with excellent low cycle fatigue property obtained by electroslag remelting, which is a steel containing, in terms of wt%, C: from 0.32 to 0.42%, Si: from 0.10 to 1.20%, Mn: from 0.10 to 0.50%, Cr: from 4.50 to 5.50%, Mo: from 1.00 to 1.50%, V: from 0.30 to 0.80%, P: 0.010% or less, S: 0.003% or less, Ni: 1.00% or less, Co: 1.00% or less, and W: 1.00% or less, with the balance being Fe and impurities.

35 **[0006]** Patent Document 4 discloses a hot work tool steel succeeded in enhancing all of wear resistance, cracking resistance and chipping resistance of a practical die, which is a steel containing, in terms of wt%, C: from 0.15 to 0.80%, Si: less than 0.10%, Mn: 3.0% or less, one member or two or members out of Ni: 4.0% or less, Cr: 10.0% or less and Cu: 3.0% or less, one member or two or more members out of Mo: 5.0% or less, W: 5.0% or less, V: 3.0% or less, Ti: 1.0% or less, Nb: 1.0% or less, Zr: 1.0% or less and Co: 5.0% or less, S: 0.005% or less, P: 0.015% or less, and O: 0.0030% or less, with the balance being Fe and impurities.

40 **[0007]** Patent Document 5 discloses an alloy tool steel excellent in hot workability and fatigue property, which is a steel containing, in terms of wt%, C: from 0.35 to 1.50%, Si: from 0.1 to 2.0%, Mn: from 0.1 to 1.5%, Cr: from 2.0 to 10.0%, one member or two or more members out of 2Mo+W: from 1.5 to 30.0% and V: from 0.5 to 5.0%, REM: from 0.001 to 0.60%, and one member or two or more members out of Co: from 1.0 to 20.0%, Ni: from 0.01 to 2.0%, Cu: from 0.25 to 1.0% and B: from 0.001 to 0.050%, and being bound by a restriction to S: 0.0020% or less, O: 0.0030% or less, N: 0.020% or less, Al: 0.020% or less and P: 0.020% or less, with the balance substantially being Fe.

45 **[0008]** Patent Document 6 discloses a die steel succeeded in improving the thermal fatigue property and softening resistance and thereby making it possible to suppress heat checking and cracking of a cooling water hole and enhance the die life, which is a steel containing, in terms of mass%, C: from 0.1 to 0.6%, Si: from 0.01 to 0.8%, Mn: from 0.1 to 2.5%, Cu: from 0.01 to 2.0%, Ni: from 0.01 to 2.0%, Cr: from 0.1 to 2.0%, Mo: from 0.01 to 2.0%, one member or two or more members out of V, W, Nb and Ta: from 0.01 to 2.0% in total, Al: from 0.002 to 0.04%, N: from 0.002 to 0.04%, and O: 0.005% or less, with the balance being Fe and unavoidable impurities.

50 **[0009]** Patent Document 7 discloses an inexpensive die steel for plastic molding, satisfying both machinability and thermal conductivity, which is a steel containing C: from 0.25 to 0.45%, Si: less than 0.3%, Mn: from 0.5 to 2%, S: from 0.01 to 0.05%, and sol. Al: 0.02% or less, with the balance being Fe and impurities, wherein one or more of Cr of up to 0.5% and V of less than 0.2% may be contained.

55 **[0010]** Patent Document 8 discloses a prehardened steel for a die-casting die, enabling extension of the die-casting die life, which is a steel containing, in terms of the content by mass, from 0.15 to 0.35% of C, from 0.05% to less than 0.20% of Si, from 0.05 to 1.50% of Mn, 0.020% or less of P, 0.013% or less of S, 0.10% or less of Cu, 0.20% or less of Ni, from 0.20 to 2.50% of Cr, from 0.50 to 3.00% of Mo, from 0.05 to 0.30% in total of V and Nb, from 0.020 to 0.040%

of Al, 0.003% or less of O, and from 0.010 to 0.020% of N, with the balance substantially being Fe.

[0011] Patent Document 9 discloses a steel for press die, having high thermal fatigue property, which is a steel containing C: from 0.10 to 0.45 wt%, Si: from 0.10 to 2.0 wt%, Mn: from 0.10 to 2.0 wt%, Mo: from 0.50 to 3.0 wt% and V: from 0.50 to 0.80 wt%, and further containing Cr: from 3.0 to 8.0 wt% and Ni: from 0.05 to 1.2 wt%, with the balance being Fe and unavoidable impurities.

[0012] Patent Document 10 discloses a die steel with good spheroidization annealability and good machinability, ensuring that satisfactory quenching and desired impact value are obtained and the die life is enhanced, which is a steel having a composition containing, in terms of mass%, C: from 0.2 to 0.6%, Si: from 0.01 to 1.5%, Mn: from 0.1 to 2.0%, Cu: from 0.01 to 2.0%, Ni: from 0.01 to 2.0%, Cr: from 0.1 to 8.0%, Mo: from 0.01 to 5.0%, one member or two or more members out of V, W, Nb and Ta: from 0.01 to 2.0% in total, Al: from 0.002 to 0.04%, N: from 0.002 to 0.04%, and the balance being Fe and unavoidable impurities.

[0013]

[Patent Document 1] JP-A-06-322483 (the term "JP-A" as used herein means an "unexamined published Japanese patent application")

[Patent Document 2] JP-A-03-000402

[Patent Document 3] JP-A-07-062494

[Patent Document 4] JP-A-60-059053

[Patent Document 5] JP-A-08-100239

[Patent Document 6] JP-A-2008-056982

[Patent Document 7] JP-A-2004-183008

[Patent Document 8] JP-A-2005-307242

[Patent Document 9] JP-A-64-062444

[Patent Document 10] JP-A-2008-121032

[0014] However, the steels disclosed in Patent Documents 1 to 10 are not a steel satisfying both the thermal conductivity and the impact value that the present invention intends to achieve.

For example, in Patent Document 1, the thermal conductivity is neither suggested nor disclosed, and decrease of impact value due to excess V may be feared.

In Patent Document 2, reduction of thermal conductivity due to excess Si or decrease of impact value due to too little Mn or too little Cr may be feared.

Also in Patent Documents 3 to 5, thermal conductivity is neither suggested nor disclosed. In Patent Document 3, insufficient transformation behavior (hardenability) and decrease of impact value due to too little Mn may be feared. In Patent Document 4, decrease of impact value due to too little Cr or too little or excess V may be feared. In Patent Document 5, insufficient transformation behavior (hardenability) and decrease of impact value due to too little Mn, reduction of high-temperature strength due to too little Mo, or decrease of impact value due to too little or excess V may be feared. In Patent Documents 6 to 8, deterioration of transformation behavior (hardenability) or decrease of hardness or impact value due to too little Cr may be feared.

In Patent Documents 9 and 10, reduction of thermal conductivity due to excess Si or decrease of impact value due to too little Cr may be feared.

SUMMARY OF THE INVENTION

[0015] The present invention has been made in consideration of these circumstances, and an object of the present invention is to provide a hot work tool steel assured of machinability industrially allowing for working into a die shape and enhanced in the thermal conductivity and impact value as compared with general-purpose die steel (for example, JIS SKD61), and a steel product using the same.

[0016] The general-purpose die steel (JIS SKD61) has excellent machinability but is low in the thermal conductivity and impact value. Therefore, the present inventors have made intensive studies to increase the thermal conductivity and impact value to be higher than in the general-purpose die steel while maintaining the machinability industrially allowing for working into a die shape. As a result, it has been found that the thermal conductivity can be increased by setting the Si amount to be low and at the same time, the impact value can be raised by adjusting the Mn amount, Cr amount, Mo amount and V amount. The present invention has been accomplished based on this finding.

[0017] In order to achieve the above-mentioned object, the present invention provides a hot work tool steel containing:

0.20≤C≤0.50 mass%,

0.01≤Si<0.25 mass%,

0.50<Mn≤1.50 mass%,

5.24<Cr≤9.00 mass%,
1.24<Mo<2.95 mass%, and
0.30<V<0.70 mass%,

with the balance being Fe and unavoidable impurities.

Herein, examples of the unavoidable impurities include W<0.30 mass%, Co<0.30 mass%, Nb<0.004 mass%, Ta<0.004 mass%, Ti<0.004 mass%, Zr<0.004 mass%, Al<0.004 mass%, N<0.004 mass%, Cu<0.15 mass%, Ni<0.15 mass%, B<0.0010 mass%, S<0.010 mass%, Ca<0.0005 mass%, Se<0.03 mass%, Te<0.005 mass%, Bi<0.01 mass%, Pb<0.03 mass%, Mg<0.005 mass%, and O<0.0080 mass%.

[0018] The hot work tool steel according to the present invention may further contains:

0.30≤W≤4.00 mass%.

[0019] The hot work tool steel according to the present invention may further contains:

0.30≤Co≤3.00 mass%.

[0020] The hot work tool steel according to the present invention may further contains at least one element selected from the group consisting of:

0.004≤Nb≤0.100 mass%,
0.004≤Ta≤0.100 mass%,
0.004≤Ti≤0.100 mass%,
0.004≤Zr≤0.100 mass%,
0.004≤Al≤0.050 mass%, and
0.004≤N≤0.050 mass%.

[0021] The hot work tool steel according to the present invention may further contains at least one element selected from the group consisting of:

0.15≤Cu≤1.50 mass%,
0.15≤Ni≤1.50 mass%, and
0.0010≤B≤0.0100 mass%.

[0022] The hot work tool steel according to the present invention may further contains at least one element selected from the group consisting of:

0.010≤S≤0.500 mass%,
0.0005≤Ca≤0.2000 mass%,
0.03≤Se≤0.50 mass%,
0.005≤Te≤0.100 mass%,
0.01≤Bi≤0.30 mass%, and
0.03≤Pb≤0.50 mass%.

[0023] The hot work tool steel to the present invention preferably has a thermal conductivity of 28 W/m/K or more at a room temperature.

A steel product according to the present invention uses the hot work tool steel according to the present invention.

The term "steel product" as used herein indicates, for example, a die-casting die, a hot forging die, or a warm forging die, but the present invention is not limited thereto.

[0024] The hot work tool steel of the present invention and a steel product using the same have the above-described component composition and therefore, there is produced an effect of ensuring high thermal conductivity and high impact value as compared with the general-purpose die steel (for example, JIS SKD61) while keeping machinability industrially allowing for working into a die shape.

That is, in the hot work tool steel of the present invention, the Si amount is optimized and this produces an effect of ensuring a higher thermal conductivity than that of the general-purpose die steel (for example, JIS SKD61) while keeping machinability industrially allowing for working into a die shape. Also, in the hot work tool steel, the Mn amount, Cr amount, Mo amount and V amount are optimized and this produces an effect of ensuring low transformation temperature of bainitic transformation under the condition of small cooling rate (so called hardenability) and high impact value. Therefore,

the hot work tool steel of the present invention hardly causes soldering or heat checking, so that a long die life can be obtained and reduction of production cost and enhancement of productivity in die casting or hot and/or warm forging can be attained.

5 BRIEF DESCRIPTION OF THE DRAWINGS

[0025]

- Fig. 1 is a graph showing the relationship between the machinability and the Si content.
 Fig. 2 is a graph showing the relationship between the thermal conductivity and the Si content.
 Fig. 3 is a graph showing the relationship between the impact value and the Mn content.
 Fig. 4 is a graph showing the relationship between the thermal conductivity and the Mn content.
 Fig. 5 is a graph showing the relationship between the impact value and the Cr content.
 Fig. 6 is a graph showing the relationship between the thermal conductivity and the Cr content.
 Fig. 7 is a graph showing the relationship between the strength at 600°C (high-temperature strength) and the Mo content.
 Fig. 8 is a graph showing the relationship between the impact value and the V content.

BEST MODE FOR CARRYING OUT THE INVENTION

[0026] The hot work tool steel according to one embodiment of the present invention and a steel product using the same are described below.

(Component Composition of Hot Work Tool Steel and Reasons for Limitations Therein)

[0027] The hot work tool steel according to this embodiment contains, as essential elements, C, Si, Mn, Cr, Mo and V, with the balance being Fe and unavoidable impurities. The hot work tool steel according to this embodiment contains, for example, W, Co, Nb, Ta, Ti, Zr, Al, N, Cu, Ni, B, S, Ca, Se, Te, Bi, Pb, Mg and O as unavoidable impurities. Herein, in the present specification, all the percentages defined by mass are the same as those defined by weight, respectively.

(1) $0.20 \leq C \leq 0.50$ mass%

[0028] C is an essential element necessary for adjusting the strength of the steel. If the C amount is less than 0.20 mass%, the required hardness of 36 HRC or more can be hardly obtained, whereas if the C amount exceeds 0.50 mass%, the hardness tends to be saturated and at the same time, the carbide amount becomes excessive to deteriorate the fatigue strength or impact value. For this reason, the C amount is set to $0.20 \leq C \leq 0.50$ mass%. Because of excellent balance of hardness, fatigue strength and impact value, the C amount is preferably $0.24 \leq C \leq 0.46$ mass%, more preferably $0.28 < C \leq 0.42$ mass%.

(2) $0.01 \leq Si < 0.25$ mass%

[0029] Si is an essential element necessary for adjusting the machinability and thermal conductivity of the steel. If the Si amount is less than 0.01 mass%, deterioration of machinability is pronounced and working into a die shape becomes very difficult. If the Si amount is 0.25 mass% or more, the thermal conductivity is greatly reduced. For this reason, the Si amount is set to $0.01 \leq Si < 0.25$ mass%. The Si amount is preferably $Si \leq 0.20$ mass%, more preferably $Si < 0.10$ mass%, where a high thermal conductivity is obtained.

(3) $0.50 < Mn \leq 1.50$ mass%

[0030] Mn is an essential element for improving the transformation behavior (hardenability). If the Mn amount is 0.50 mass% or less, the effect of decreasing the transformation temperature and refining microstructure is insufficient and therefore it is difficult to ensure hardness or impact value. If the Mn amount exceeds 1.50 mass%, not only the impact value is rather decreased but also a high thermal conductivity can be hardly maintained. For this reason, the Mn amount is set to $0.50 < Mn \leq 1.50$ mass%. The Mn amount is preferably $0.66 < Mn \leq 1.20$ mass% where the hardness and impact value can be ensured and at the same time, a high thermal conductivity can be obtained.

(4) $5.24 < \text{Cr} \leq 9.00$ mass%

[0031] Cr is an essential element for improving the transformation behavior (hardenability) and at the same time, increasing the strength of the steel by forming a carbide. If the Cr amount is 5.24 mass% or less, the effect of decreasing the transformation temperature and refining microstructure is not sufficient and the hardness and impact value cannot be sufficiently obtained. Furthermore, the corrosion resistance required of a die-casting die that is exposed to a corrosion environment is higher as the Cr amount is larger. On the other hand, if the Cr amount exceeds 9.00 mass%, it becomes difficult to maintain a high thermal conductivity. For this reason, the Cr amount is set to $5.24 < \text{Cr} \leq 9.00$ mass%. Also, the Cr amount is preferably $5.40 < \text{Cr} \leq 7.00$ mass%, more preferably $5.55 \leq \text{Cr} \leq 6.50$ mass%, where the hardness, impact value and corrosion resistance are ensured and at the same time, a high thermal conductivity is obtained.

(5) $1.24 < \text{Mo} < 2.95$ mass%

[0032] Mo is an essential element not only for improving the transformation behavior (hardenability), but also for increasing the strength of the steel by forming a carbide, particularly for enhancing the high-temperature strength. If the Mo amount is 1.24 mass% or less, satisfactory high-temperature strength is not obtained, whereas if the Mo amount is 2.95 mass% or more, the high-temperature strength tends to be saturated and at the same time, a significant rise in the cost impairs the profitability. For this reason, the Mo amount is set to $1.24 < \text{Mo} < 2.95$ mass%. Also, the Mo amount is preferably $1.37 < \text{Mo} \leq 2.80$ mass%, more preferably $1.50 \leq \text{Mo} \leq 2.50$ mass%.

(6) $0.30 < \text{V} < 0.70$ mass%

[0033] V is an essential element not only for improving the transformation behavior (hardenability), but also for increasing the strength of the steel by forming a carbide, particularly for enhancing the high-temperature strength. If the V amount is 0.30 mass% or less, austenitic grain is readily coarsened at the quenching to decrease the impact value, whereas if the V amount is 0.70 mass% or more, the coarse carbide amount becomes excessive and this deteriorates the impact value. For this reason, the V amount is set to $0.30 < \text{V} < 0.70$ mass%. Also, the V amount is preferably $0.40 \leq \text{V} \leq 0.67$ mass%, more preferably $0.50 \leq \text{V} \leq 0.64$ mass%, where softening resistance can be ensured and at the same time, fatigue strength and impact value can be satisfactorily obtained.

(7) Unavoidable impurities:

[0034] $\text{W} < 0.30$ mass%, $\text{Co} < 0.30$ mass%, $\text{Nb} < 0.004$ mass%, $\text{Ta} < 0.004$ mass%, $\text{Ti} < 0.004$ mass%, $\text{Zr} < 0.004$ mass%, $\text{Al} < 0.004$ mass%, $\text{N} < 0.004$ mass%, $\text{Cu} < 0.15$ mass%, $\text{Ni} < 0.15$ mass%, $\text{B} < 0.0010$ mass%, $\text{S} < 0.010$ mass%, $\text{Ca} < 0.0005$ mass%, $\text{Se} < 0.03$ mass%, $\text{Te} < 0.005$ mass%, $\text{Bi} < 0.01$ mass%, $\text{Pb} < 0.03$ mass%, $\text{Mg} < 0.005$ mass%, $\text{O} < 0.0080$ mass% and so on.

In the case where the amounts of W, Co, Nb, Ta, Ti, Zr, Al, N, Cu, Ni, B, S, Ca, Se, Te, Bi, Pb, Mg, O, etc. are in the above-described ranges, respectively, these elements are included as the unavoidable impurities.

[0035] The hot work tool steel according to this embodiment may further contain, as selective elements:

- (a) W,
- (b) Co,
- (c) at least one element selected from the group consisting of Nb, Ta, Ti, Zr, Al and N,
- (d) at least one element selected from the group consisting of Cu, Ni and B, and/or
- (e) at least one element selected from the group consisting of S, Ca, Se, Te, Bi and Pb.

(8) $0.30 \leq \text{W} \leq 4.00$ mass%

[0036] W is a selective element that can be added so as to increase the strength by the precipitation of a carbide (precipitation hardening). If the W amount is less than 0.30 mass%, the effect of increasing the strength is small, whereas if the W amount exceeds 4.00 mass%, this incurs saturation of the effect and a significant rise in cost. For this reason, the W amount is set to $0.30 \leq \text{W} \leq 4.00$ mass%.

(9) $0.30 \leq \text{Co} \leq 3.00$ mass%

[0037] Co is a selective element that can be added so as to increase the strength by the solid solution in the matrix (solid solution hardening). If the Co amount is less than 0.30 mass%, the effect of increasing the strength is small, whereas if the Co amount exceeds 3.00 mass%, this incurs saturation of the effect and a significant rise in cost. For this

reason, the Co amount is set to $0.30 \leq \text{Co} \leq 3.00$ mass%.

[0038]

(10) At least one element selected from the group consisting of:

$0.004 \leq \text{Nb} \leq 0.100$ mass%,

$0.004 \leq \text{Ta} \leq 0.100$ mass%,

$0.004 \leq \text{Ti} \leq 0.100$ mass%,

$0.004 \leq \text{Zr} \leq 0.100$ mass%,

$0.004 \leq \text{Al} \leq 0.050$ mass%, and

$0.004 \leq \text{N} \leq 0.050$ mass%.

Nb, Ta, Ti, Zr, Al and N are a selective element that can be added so as to increase the strength and toughness by austenitic grains at the quenching (grain refining). As regards all of these elements, if the amount added is less than the predetermined amount, the effect of improving the strength and toughness is small, whereas if it exceeds the predetermined amount, a carbide, a nitride or an oxide is excessively produced, and this rather incurs reduction of toughness.

[0039]

(11) At least one element selected from the group consisting of:

$0.15 \leq \text{Cu} \leq 1.50$ mass%,

$0.15 \leq \text{Ni} \leq 1.50$ mass%, and

$0.0010 \leq \text{B} \leq 0.0100$ mass%.

Cu, Ni and B are a selective element that can be added so as to improve the transformation behavior (hardenability). As regards all of these elements, if the amount added is less than the predetermined amount, the effect of improving the transformation behavior (hardenability) is small, whereas if it exceeds the predetermined amount, the effect is saturated and the practical benefit is poor. In particular, with respect to Cu and Ni, excessive addition gives rise to reduction of the thermal conductivity.

[0040]

(12) At least one element selected from the group consisting of:

$0.010 \leq \text{S} \leq 0.500$ mass%,

$0.0005 \leq \text{Ca} \leq 0.2000$ mass%,

$0.03 \leq \text{Se} \leq 0.50$ mass%,

$0.005 \leq \text{Te} \leq 0.100$ mass%,

$0.01 \leq \text{Bi} \leq 0.30$ mass%, and

$0.03 \leq \text{Pb} \leq 0.50$ mass%.

S, Ca, Se, Te, Bi and Pb are a selective element that can be added so as to improve the machinability (machinability enhancement). As regards all of these elements, if the amount added is less than the predetermined amount, the effect of improving the machinability is small, whereas if it exceeds the predetermined amount, hot workability is significantly deteriorated to cause frequent occurrence of cracking in plastic working and therefore the productivity and yield are reduced.

In this regard, with regard to each element contained in the steel of the invention, according to an embodiment, the minimal amount thereof present in the steel is the smallest non-zero amount used in the Examples of the developed steels as summarized in Table 1 and 2. According to a further embodiment, the maximum amount thereof present in the steel is the maximum amount used in the Examples of the developed steels as summarized in Table 1 and 2.

(Production Method)

[0041] The steel according to this embodiment can be obtained, for example, by the following procedure, but the present invention is not limited thereto.

(1) Casting

[0042] The raw materials blended to give the predetermined components above are melted, and the melt is cast in a casting mold to obtain an ingot.

(2) Homogenization Heat Treatment/Hot Working

[0043] A homogenization heat treatment and hot working are performed to homogenize the components of the obtained ingot and break the cast structure. As for the conditions of the homogenization heat treatment and hot working, optimal conditions for each processing are preferably selected according to the components.

The homogenization heat treatment is usually performed by holding the ingot at 1,100 to 1,500°C for approximately from 10 to 30 hours.

The hot working is usually performed at 1,000 to 1,300°C, and after the completion of working, the ingot is air-cooled.

(3) Tempering/Spheroidization Annealing/Rough Machining

[0044] The steel according to this embodiment has relatively good transformation behavior (hardenability) and therefore, is often hardened at the air cooling after hot working due to occurrence of bainitic transformation or martensitic transformation. Therefore, the material is preferably softened by performing tempering and spheroidization annealing after the working and then subjected to rough machining.

As for the tempering conditions, optimal conditions are preferably selected according to the components. The tempering is usually performed by holding the material at 600 to 750°C for approximately from 1 to 10 hours.

The spheroidization annealing is preferably performed to give a steel hardness of approximately from 90 to 97 HRB.

The spheroidization annealing is usually performed by holding the material at 800 to 950°C for approximately from 1 to 10 hours and then cooling it at a rate of 5 to 30°C per 1 hour.

The rough machining is performed by mechanically working the softened material into a predetermined shape.

(4) Thermal Treatment (Quenching/Tempering)

[0045] The thermal treatment is performed for adjusting the roughly machined material to a desired hardness. As for the quenching conditions and tempering conditions, optimal conditions for each processing are preferably selected according to the components and required properties.

The quenching is usually performed by holding the material at 1,000 to 1,050°C for 0.5 to 5 hours and then rapidly cooling it. The rapidly cooling method is not particularly limited, and an optimal method is preferably selected according to the purpose. Examples of the rapidly cooling method include water cooling, oil cooling and air blast cooling.

The tempering is usually performed by holding the material at 500 to 650°C for 1 to 10 hours.

By passing through these steps (1) to (4), a steel assured of a high thermal conductivity and a high impact value as compared with the general-purpose die steel (for example, JIS SKD61) while keeping machinability industrially allowing for working into a die shape, is obtained.

(5) Finish Machining

[0046] The material thermally treated to a desired hardness is subjected to finish machining.

By passing the step (5), a steel product using the hot work tool steel according to this embodiment is obtained.

(Mode of Operation)

[0047] In the hot work tool steel according to this embodiment, the Si amount is optimized, so that the steel can be higher in the thermal conductivity than the general-purpose die steel (for example, JIS SKD61) while keeping machinability industrially allowing for working into a die shape. Also, in the hot work tool steel according to this embodiment, the Mn amount, Cr amount, Mo amount, V amount and the like are optimized, so that the steel can have improved transformation behavior and high impact value. Therefore, the hot work tool steel according to this embodiment hardly causes soldering or heat checking. As a result, a long die life is obtained, and reduction of production cost and enhancement of productivity in die casting or hot and/or warm forging can be attained.

EXAMPLES

(Example A)

- 5 **[0048]** For producing each invention steel in Example B below, Examples 1 to 5 were performed to examine the preferred Si amount, Mn amount, Cr amount, Mo amount and V amount.

(Example 1: Examination of Si Amount)

- 10 **[0049]** The preferred Si amount was examined and is described below by referring to Figs. 1 and 2.
Fig. 1 shows the distance machined by a cutting tool until the end of its life, with respect to the Si amount when cutting a steel composed of 0.33 mass% of C, 0.82 mass% of Mn, 5.73 mass% of Cr, 1.63 mass% of Mo, 0.62 mass% of V and x mass% of Si. In Fig. 1, the numerical values at each plotted point are such that the numerical value on the upper side indicates the x value (mass%) and the numerical value on the lower side indicates the distance (mm) machined.
- 15 The specimen for evaluation of machinability was a square bar of 55 mm × 55 mm × 200 mm (produced by the same procedure as in Example B and softened to a hardness of 90 to 97 HRB by spheroidization annealing), and the time when the maximum wear volume on the side clearance face of the cutting tool reached 300 μm was judged as the end of life. A larger machined distance is indicative of better machining and is preferred.
- 20 According to Fig. 1, the machined distance is increased with an increase of the Si amount and therefore, from the standpoint of enhancing machinability, the Si amount is preferably larger. According to Fig. 1, since the machined distance is extremely small when the Si amount is less than 0.01 mass%, the Si amount is suitably 0.01 mass% or more for ensuring machinability. According to Fig. 1, the effect of improving the machinability is prominent when the Si amount is from 0.01 to 0.24 mass% (less than 0.25 mass%), and becomes gentle when the Si amount exceeds 0.24 mass%.
- 25 **[0050]** A round bar of φ 11 mm × 50 mm using the same material as in Fig. 1 was heated at 1,030°C and then treated to 48 HRC through rapid cooling and tempering. From this round bar, a specimen of φ 10 mm × 2 mm for measurement of thermal conductivity was produced. Fig. 2 shows the thermal conductivity measured at room temperature by a laser flash method, with respect to the Si amount. In Fig. 2, the numerical values at each plotted point are such that the numerical value on the upper side indicates the x value (mass%) and the numerical value on the lower side indicates the thermal conductivity (W/m/K). A larger thermal conductivity is indicative of higher cooling ability of a die formed and is preferred.
- 30 According to Fig. 2, the thermal conductivity is reduced with an increase of the Si amount but when the Si amount is on the order of exceeding 0.09 mass% (less than 0.10 mass%), a thermal conductivity of 28 W/m/K or more leading to a remarkable improvement of the cooling ability as compared with the general-purpose die steel (JIS SKD61 (thermal conductivity: 24 W/m/K)) is obtained. Incidentally, according to Fig. 2, a high thermal conductivity of 30.7 W/m/K or more is obtained when the Si amount is from 0.007 to 0.09 mass%, and a good thermal conductivity of 28.1 W/m/K or more is obtained when the Si amount is from 0.09 to 0.24 mass%.
- 35 In view of keeping the machinability industrially allowing for working into a die shape, the Si amount can be less than 0.25 mass%.

40 (Example 2: Examination of Mn Amount)

- [0051]** The preferred Mn amount was examined and is described below by referring to Figs. 3 and 4.
Fig. 3 plots the impact value at room temperature of a steel composed of 0.33 mass% of C, 0.08 mass% of Si, 5.75 mass% of Cr, 1.60 mass% of Mo, 0.60 mass% of V and x mass% of Mn, with respect to the Mn amount. In Fig. 3, the numerical values at each plotted point are such that the numerical value on the upper side indicates the x value (mass%) and the numerical value on the lower side indicates the impact value (J/cm²). The specimen for evaluation of impact value was a square bar of 11 mm × 11 mm × 55 mm (produced by the same procedure as in Example B and softened to a hardness of 90 to 97 HRB by spheroidization annealing), which was heated at 1,030°C and then treated to 49 HRC through rapid cooling and tempering. A JIS No. 3 impact test specimen of 10 mm × 10 mm × 55 mm was produced from the square bar above and measured for the impact value. A larger impact value is indicative of higher cracking resistance of a die formed and is preferred.
- 45 According to Fig. 3, it is understood that an impact value of 30 J/cm² or more is obtained when the Mn amount is 0.45 mass% and 0.55 mass%. Therefore, a value of 0.50 mass% in-between the Mn amounts of 0.45 mass% and 0.55 mass% is taken as the lower limit of the Mn amount. Also, according to Fig. 3, an impact value of 34.5 J/cm² or more is obtained when the Mn amount is 0.7 mass% or more. Therefore, a case of containing this element in excess of 0.66 mass% that is in-between the Mn amounts of 0.55 mass% and 0.7 mass% can be selected as a preferred embodiment. However, according to Fig. 3, it is seen that when the Mn amount exceeds 1.50 mass%, the impact value is decreased, though the value is kept at a good level.
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[0052] Fig. 4 plots the thermal conductivity at room temperature of the same material as in Fig. 3, with respect to the Mn amount. In Fig. 4, the numerical values at each plotted point are such that the numerical value on the upper side indicates the x value (mass%) and the numerical value on the lower side indicates the thermal conductivity (W/m/K). The measurement of the thermal conductivity was performed by a laser flash method similarly to Example 1.

According to Fig. 4, the thermal conductivity is reduced with an increase of the Mn amount and when the Mn amount exceeds 1.50 mass%, a thermal conductivity of 28 W/m/K or more leading to a remarkable improvement of the cooling ability as compared with JIS SKD61 (thermal conductivity: 24 W/m/K) is not obtained. According to Fig. 4, the Mn amount can be 1.50 mass% or less for obtaining a thermal conductivity of 28 W/m/K or more and can be 1.20 mass% or less for obtaining 29 W/m/K or more.

(Example 3: Examination of Cr Amount)

[0053] The preferred Cr amount was examined and is described below by referring to Figs. 5 and 6.

Fig. 5 plots the impact value at room temperature of a steel composed of 0.33 mass% of C, 0.08 mass% of Si, 0.84 mass% of Mn, 1.62 mass% of Mo, 0.61 mass% of V and x mass% of Cr and treated to 49 HRC, with respect to the Cr amount. In Fig. 5, the numerical values at each plotted point are such that the numerical value on the upper side indicates the x value (mass%) and the numerical value on the lower side indicates the impact value (J/cm²). The production of specimen and the measurement of impact value were performed in the same manner as in Example 2.

According to Fig. 5, the impact value is increased with an increase of the Cr amount. In particular, when the Cr amount exceeds 5 mass%, the effect of this element is prominent. According to Fig. 5, it is understood that the Cr amount can be more than 5.24 mass% for obtaining an impact value of 27.8 J/cm² or more. Therefore, in view of ensuring the impact value, the lower limit of the Cr amount is set to be 5.24 mass% or more. Also, according to Fig. 5, when the Cr amount is less than 5 mass%, the decrease of impact value is pronounced.

[0054] Fig. 6 plots the thermal conductivity at room temperature of a steel composed of 0.22 mass% of C, 0.22 mass% of Si, 0.52 mass% of Mn, 1.62 mass% of Mo, 0.61 mass% of V and x mass% of Cr, with respect to the Cr amount. In Fig. 6, the numerical values at each plotted point are such that the numerical value on the upper side indicates the x value (mass%) and the numerical value on the lower side indicates the thermal conductivity (W/m/K). The measurement of the thermal conductivity was performed by a laser flash method similarly to Example 1.

According to Fig. 6, the thermal conductivity is reduced with an increase of the Cr amount. According to Fig. 6, the Cr amount can be 9.00 mass% or less for obtaining a thermal conductivity of 27.5 W/m/K or more leading to an improvement of the cooling ability as compared with JIS SKD61 (thermal conductivity: 24 W/m/K), can be 7.00 mass% or less for obtaining 30.1 W/m/K or more leading to a remarkable improvement of the cooling ability, and can be 6.50 mass% or less for obtaining 31 W/m/K or more.

(Example 4: Examination of Mo Amount)

[0055] The preferred Mo amount was examined and is described below by referring to Fig. 7.

Fig. 7 shows the high-temperature strength (deformation resistance at 600°C) of a steel composed of 0.33 mass% of C, 0.07 mass% of Si, 0.83 mass% of Mn, 5.74 mass% of Cr, 0.59 mass% of V and x mass% of Mo, with respect to the Mo amount.

In Fig. 7, the numerical values at each plotted point are such that the numerical value on the upper side indicates the x value (mass%) and the numerical value on the lower side indicates the high-temperature strength (MPa). The specimen for measurement of deformation resistance was a round bar of ϕ 15 mm $\times$ 50 mm (produced by the same procedure as in Example B and softened to a hardness of 90 to 97 HRB by spheroidization annealing), which was heated at 1,030°C and then treated to 45 HRC through rapid cooling and tempering. From this round bar, a specimen of ϕ 14 mm $\times$ 21 mm for measurement of deformation resistance was produced. The specimen was heated to 600°C at 5°C/s and after holding for 100 s, measured for the deformation resistance by working it at a strain rate of 10 s⁻¹.

[0056] The term "deformation resistance" as used herein means a power per unit area necessary for deforming a material. More specifically, the "deformation resistance" indicates K_f determined as $K_f = p_w / a_w$ from a power p_w during working at a strain rate 10 s⁻¹ and a contact area a_w perpendicular to the power (hereinafter, the "deformation resistance" is used in the same meaning).

[0057] The deformation resistance measured in this way is defined as a strength at 600°C (high-temperature strength) and plotted with respect to the Mo amount (see, Fig. 7). A higher deformation resistance is indicative of higher strength and in turn less wearing and is therefore preferred.

According to Fig. 7, the high-temperature strength is increased with an increase of the Mo amount. In particular, when the Mo amount is more than 1.24 mass%, the increase of high-temperature strength enables obtaining a relatively high degree of high-temperature strength (>970 MPa). According to Fig. 7, when the Mo amount is from more than 1.24 mass% to 3 mass%, the increase of high-temperature strength becomes gentle, and when the Mo amount is 3 mass%

or more, the increase of high-temperature strength is saturated. According to Fig. 7, the Mo amount can be more than 1.24 mass% for obtaining a high-temperature strength of 971 MPa or more, can be more than 1.37 mass% for obtaining 974 MPa or more, and can be 1.50 mass% or more for obtaining 977 MPa or more. However, an Mo amount of 2.95 mass% or more incurs a significant rise in cost. Therefore, in view of cost reduction, the Mo amount is preferably less than 2.99 mass%, more preferably 2.80 mass% or less, still more preferably 2.50 mass% or less.

(Example 5: Examination of V Amount)

[0058] The preferred V amount was examined and is described below by referring to Fig. 8.

Fig. 8 shows the impact value of a steel composed of 0.34 mass% of C, 0.09 mass% of Si, 0.82 mass% of Mn, 5.75 mass% of Cr, 1.63 mass% of Mo and x mass% of V and treated to 48 HRC, with respect to the V amount. In Fig. 8, the numerical values at each plotted point are such that the numerical value on the upper side indicates the x value (mass%) and the numerical value on the lower side indicates the impact value (J/cm²). The production of specimen and the measurement of impact value were performed in the same manner as in Example 2.

According to Fig. 8, when the V amount is varied in the range of from 0.1 to 1 mass%, a good impact value (20 J/cm² or more) is obtained irrespective of the amount. According to Fig. 8, the deflection point exists in the vicinity of a V amount of 0.30 mass% and in the vicinity of a V amount of 0.70 mass%. Therefore, when the V amount is set to be from more than 0.30 mass% to less than 0.70 mass%, this is considered to contribute to improvement of transformation behavior (hardenability) and realization of high strength of the steel by the formation of a carbide. On the other hand, according to Fig. 8, when the V amount is 0.30 mass% or less, the decrease of impact value is pronounced and when the V amount is 0.70 mass% or more, the rise in material cost becomes a problem in addition to the decrease of the impact value. Therefore, the V amount is preferably 0.30<V<0.70 mass%. According to Fig. 8, the V amount can be 0.40 mass% or more for obtaining an impact value of 31 J/cm² or more, and can be 0.50 mass% or more for obtaining 34 J/cm² or more.

(Example B)

[0059] Based on the examination results of Example A, invention steels and comparison steels were produced and evaluated, and this is described below.

(Production of Specimen and Die-Casting Die)

[0060] With respect to Examples and Comparative Examples (Comparative Steel A10 is JIS SKD61) shown in Tables 1 and 2, each steel species was melted in vacuum, and the melt was cast in a casting mold to obtain an ingot of 6 ton. The obtained ingot was subjected to a homogenization treatment at 1,240°C. Thereafter, a rectangular block having a cross-section of 310 mm × 660 mm was produced by hot forging.

Subsequently, the rectangular block was tempered at 700°C, then heated to 900°C and gradually cooled, whereby the rectangular block was softened to a hardness of 90 to 97 HRB. From the resulting rectangular block, a die-casting die of about 700 kg was machined out.

This die-casting die was heated to 1,030°C in vacuum and after holding for 1 hour, quenched by spraying a nitrogen gas. The die-casting die was then treated to about 42 HRC through tempering at 580 to 610°C.

After the thermal treatment, various specimens were cut out from the die-casting die. Also, the die-casting die was subjected to finish machining, whereby a die-casting die of about 650 kg was produced.

[0061]

Table 1

Component Composition (unit: mass%)																								
	No.	C	Si	Mn	Cr	Mo	V	W	Co	Nb	Ta	Ti	Zr	Al	N	B	Cu	Ni	S	Ca	Se	Te	Bi	Pb
Invention Steel	A01	0.22	0.22	0.52	8.91	1.98	0.59	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	A02	0.21	0.23	0.52	7.90	2.01	0.60	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	A03	0.22	0.22	0.53	6.85	2.02	0.59	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	A04	0.21	0.22	1.46	6.47	1.25	0.32	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	A05	0.49	0.24	0.52	5.25	2.91	0.69	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	A06	0.45	0.18	0.63	5.41	1.38	0.41	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	A07	0.25	0.14	1.31	6.28	2.75	0.66	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	A08	0.29	0.09	0.70	6.06	2.43	0.64	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	A09	0.32	0.07	0.75	5.89	2.03	0.63	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	A10	0.34	0.08	0.82	5.73	1.62	0.62	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	A11	0.38	0.06	0.95	5.64	1.81	0.58	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	A12	0.41	0.04	1.15	5.55	1.51	0.52	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	B01	0.33	0.08	0.81	5.74	1.62	0.62	0.52	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	B02	0.34	0.08	0.83	5.72	1.60	0.59	-	1.02	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	B03	0.32	0.09	0.83	5.71	1.63	0.61	0.53	0.51	0.073	-	-	-	0.039	0.006	-	-	-	-	-	-	-	-	-
	B04	0.33	0.08	0.82	5.73	1.60	0.62	1.13	1.04	0.051	0.012	-	-	0.029	0.018	-	-	-	-	-	-	-	-	-
	B05	0.34	0.08	0.84	5.72	1.61	0.61	2.01	1.99	0.028	-	0.018	-	0.019	0.031	-	-	-	-	-	-	-	-	-
	B06	0.34	0.07	0.85	5.71	1.62	0.60	3.92	2.97	0.006	-	-	0.023	0.007	0.042	-	-	-	-	-	-	-	-	-
	C01	0.33	0.06	0.83	5.74	1.63	0.61	-	-	-	-	0.085	-	-	0.025	0.0011	-	-	-	-	-	-	-	-
	C02	0.34	0.08	0.83	5.73	1.62	0.62	-	-	-	-	0.072	-	-	0.021	0.0038	-	-	-	-	-	-	-	-
	C03	0.33	0.07	0.82	5.73	1.61	0.62	-	-	-	-	0.058	-	-	0.017	0.0066	-	-	-	-	-	-	-	-
	C04	0.34	0.07	0.84	5.73	1.64	0.62	-	-	-	-	0.041	-	-	0.012	0.0091	-	-	-	-	-	-	-	-

[0062]

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Table 2

Component Composition (unit: mass%)																								
	No.	C	Si	Mn	Cr	Mo	V	W	Co	Nb	Ta	Ti	Zr	Al	N	B	Cu	Ni	S	Ca	Se	Te	Bi	Pb
Invention Steel	D01	0.33	0.06	0.83	5.74	1.63	0.61	-	-	-	-	-	-	-	-	-	0.16	1.42	-	-	-	-	-	-
	D02	0.34	0.07	0.82	5.73	1.62	0.63	-	-	-	-	-	-	-	-	-	0.48	0.94	-	-	-	-	-	-
	D03	0.34	0.07	0.83	5.72	1.62	0.61	-	-	-	-	-	-	-	-	-	0.92	0.51	-	-	-	-	-	-
	D04	0.33	0.08	0.83	5.72	1.63	0.62	-	-	-	-	-	-	-	-	-	1.47	0.17	-	-	-	-	-	-
	E01	0.33	0.06	0.83	5.74	1.63	0.61	-	-	-	-	-	-	-	-	-	-	-	0.019	-	-	-	0.06	-
	E02	0.33	0.07	0.82	5.73	1.61	0.62	-	-	-	-	-	-	-	-	-	-	-	0.023	-	-	-	-	0.15
	E03	0.34	0.08	0.83	5.73	1.62	0.62	-	-	-	-	-	-	-	-	-	-	-	0.051	-	-	-	-	-
	E04	0.33	0.07	0.82	5.73	1.61	0.62	-	-	-	-	-	-	-	-	-	-	-	0.092	-	-	0.015	-	-
	E05	0.34	0.07	0.82	5.73	1.62	0.63	-	-	-	-	-	-	-	-	-	-	-	0.021	-	0.09	-	-	-
	E06	0.33	0.08	0.82	5.73	1.60	0.62	-	-	-	-	-	-	-	-	-	-	-	0.020	0.018	-	-	-	-
Comparison Steel	A01	0.15	0.07	0.83	5.72	1.11	0.21	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	A02	0.55	0.73	0.83	5.73	1.61	1.08	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	A03	0.33	0.38	0.82	5.72	1.63	0.62	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	A04	0.25	0.23	0.32	5.03	1.62	0.60	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	A05	0.43	0.08	1.74	5.71	1.62	0.62	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	A06	0.33	0.09	0.53	4.16	1.59	0.61	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	A07	0.33	0.08	0.82	9.60	1.61	0.62	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	A08	0.34	0.06	0.82	5.73	0.78	0.61	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	A09	0.34	0.08	0.84	5.73	3.32	0.62	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	A10	0.39	0.92	0.45	4.99	1.23	0.94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

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(Measurement and Examination of Basic Properties)

[0063] Using the specimens cut out from the die-casting die, basic properties (high-temperature strength, thermal conductivity, impact value, corrosion resistance, cost) were measured and examined.

The high-temperature strength was measured as follows. A specimen of $\phi 14 \text{ mm} \times 21 \text{ mm}$ was cut out from the die-casting die. The obtained specimen was heated to 600°C at 5°C/s and after holding for 100 s, then measured for the deformation resistance by working it at a strain rate of 10 s^{-1} . The results are shown in Table 3.

The thermal conductivity was measured as follows. A specimen of $\phi 10 \text{ mm} \times 2 \text{ mm}$ was cut out from the die-casting die, and the thermal conductivity of the obtained specimen was measured at room temperature by a laser flash method.

The results are shown in Table 3.

The impact value was measured as follows. A JIS No. 3 impact test specimen of $10 \text{ mm} \times 10 \text{ mm} \times 55 \text{ mm}$ was cut out from the die-casting die, and the impact value of the specimen was measured at room temperature. The results are shown in Table 3.

The corrosion resistance was measured as follows. A specimen was cut out from the die-casting die, a hole was provided in the specimen, and industrial water at 45°C was passed into the inside of the hole at 3.5 liter/min for 72 Hr. The generation status of rust on the hole inner surface after passing water was evaluated with an eye. The results are shown in Table 3.

[0064]

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Table 3

Basic Properties						
	No.	High Temperature	Thermal Conductivity	Impact Value	Corrosion Resistance	Cost
Invention Steel	A01	A	A (28.0)	A (34)	A	A
	A02	A	A (28.1)	A (32)	A	A
	A03	A	A (28.2)	A (30)	A	A
	A04	A	A (28.3)	A (28)	A	A
	A05	A	A (28.0)	A (36)	A	A
	A06	A	A (28.6)	A (30)	A	A
	A07	A	A (29.3)	A (35)	A	A
	A08	A	A (30.4)	A (35)	A	A
	A09	A	A (30.4)	A (35)	A	A
	A10	A	A (30.6)	A (36)	A	A
	A11	A	A (30.3)	A (34)	A	A
	A12	A	A (30.7)	A (32)	A	A
	B01	A	A (30.5)	A (35)	A	A
	B02	A	A (29.1)	A (34)	A	A
	B03	A	A (30.5)	A (35)	A	A
	B04	A	A (29.1)	A (34)	A	A
	B05	A	A (28.6)	A (33)	A	A
	B06	A	A (28.2)	A (32)	A	A
	C01	A	A (30.5)	A (36)	A	A
	C02	A	A (30.4)	A (35)	A	A
	C03	A	A (30.6)	A (36)	A	A
	C04	A	A (30.5)	A (36)	A	A
	D01	A	A (28.1)	A (35)	A	A
	D02	A	A (28.3)	A (36)	A	A
	D03	A	A (28.5)	A (35)	A	A
	D04	A	A (28.4)	A (36)	A	A
	E01	A	A (30.6)	A (27)	A	A
	E02	A	A (30.5)	A (26)	A	A
	E03	A	A (30.4)	A (21)	A	A
	E04	A	A (30.5)	A (22)	A	A
	E05	A	A (30.5)	A (27)	A	A
	E06	A	A (30.4)	A (27)	A	A

(continued)

Basic Properties						
	No.	High Temperature	Thermal Conductivity	Impact Value	Corrosion Resistance	Cost
Comparison Steel	A01	B	A (30.6)	B (19)	A	A
	A02	A	C (27.1)	B (14)	A	B
	A03	A	C (27.7)	A (30)	A	A
	A04	A	B (27.9)	B (16)	A	A
	A05	A	C (25.4)	A (23)	A	A
	A06	A	A (31.3)	B (17)	B	A
	A07	A	C (26.5)	A (34)	A	A
	A08	B	A (29.3)	A (31)	A	A
	A09	A	A (29.1)	A (25)	A	B
	A10	B	C (23.8)	B (17)	B	A

(Evaluation of Basic Properties)

[0065] The high-temperature strength was rated "good" (denoted by "A" in Table 3) when 970 MPa or more, and otherwise rated "bad" (denoted by "B" in Table 3). The thermal conductivity was rated "good" (denoted by "A" in Table 3) when 28 W/m/K or more, and otherwise rated "bad" (denoted by "C" in Table 3, but when the value is close to 28 W/m/K, this is denoted by "B"). The impact value was rated "good" (denoted by "A" in Table 3) when more than 20 J/cm², and otherwise rated "bad" (denoted by "B" in Table 3).

The invention steels exhibited good properties in all items. Also, the machinability of the invention steels was slightly inferior to the general-purpose die steel (JIS SKD61) but was at a level industrially allowing for working into a die shape and raised no problem. Incidentally, the machinability was evaluated by judging it from the working efficiency and the wear damage of the cutting tool at the practical cutting of the die-casting die. When a steel having poor machinability is cut, the cutting tool is liable to cause locally abnormal wear or chipping, and this makes it unavoidable to reduce the working efficiency due to frequent replacing of the cutting tool and increase the cost due to use of a large number of cutting tools. The working efficiency or wear damage of the cutting tool at the cutting of the invention steels was slightly poor as compared with the general-purpose steel, but the degree of deterioration was not pronounced and it was confirmed in the practical die working that the machinability of the invention steels has no problem in industry.

In the invention steels where the thermal conductivity exceeded 30 W/m/K, the Si amount was from 0.04 to 0.09 mass%, the Mn amount was from 0.70 to 1.15 mass% (from 0.70 to 0.95 mass% except for Invention Steel A12), and the Cr amount was from 5.55 to 6.06 mass% (from 5.55 to 5.89 mass% except for Invention Steel A08, and from 5.64 to 5.89 mass% further except for Invention Steel A12).

In the invention steels where the impact value was 35 J/cm² or more, the Mn amount was from 0.52 to 1.31 mass% (from 0.70 to 1.31 mass% except for Invention Steel A05), the Cr amount was from 5.25 to 6.28 mass% (from 5.71 to 6.28 mass% except for Invention Steel A05), and the V amount was from 0.61 to 0.69 mass% (from 0.61 to 0.66 mass% except for Invention Steel A05).

[0066] On the other hand, in the case of Comparison Steel A10, rating was "bad" in all items except for cost. The specimen used was a specimen cut out from a large die-casting die obliged to decrease in the quenching rate. Therefore, the impact value was low particularly in Comparison Steel A10.

Other comparison steels were better than Comparison Steel A10 (JIS SKD61) in some evaluation items, but there was not a steel species where the rating was "good" in all items.

[0067] For example, in Comparison Steel A01, the high-temperature strength was decreased due to too little C. Also, the austenitic grain was coarsened at the quenching due to too little V and the impact value was decreased.

In Comparison Steel A02, the thermal conductivity was decreased due to excess Si. Also, in Comparison Steel A02, the amount of carbide becomes excessively large due to excess C or excess V, and the impact value was decreased.

In Comparison Steel A03, the thermal conductivity was decreased due to excess Si.

In Comparison Steel A04, the quenchability was insufficient due to too little Mn, and the impact value was decreased. The thermal conductivity of Comparison Steel A04 was slightly low as compared with the invention steel. The reason therefor is considered because the Si amount in Comparison Steel A04 was relatively large and the balance of components

of Comparison Steel A04 as a whole was improper.

[0068] In Comparison Steel A05, the thermal conductivity was decreased due to excess Mn.

In Comparison Steel A06, the effect of decreasing transformation temperature under the condition of small cooling rate and refining microstructure was insufficient due to too little Cr, and the impact value was decreased.

In Comparison Steel A07, the thermal conductivity was decreased due to excess Cr.

In Comparison Steel A08, the high-temperature strength was reduced due to too little Mo.

In Comparison Steel A09, a significant rise in cost was incurred due to excess Mo.

In Comparison Steel A10, the thermal conductivity was reduced due to excess Si. Also, Comparison Steel A10 was reduced in the high-temperature strength due to too little Mo. Furthermore, in Comparison Steel A10, the carbonitride became excessive due to excess V, and the impact value was decreased.

(Actual Machine Test Using Die-Casting Die)

[0069] An actual machine test using the die-casting die was performed as follows. The die-casting die produced was mounted in a machine, and an aluminum alloy was cast. ADC12 was used for the aluminum alloy, and the temperature of the melting and holding furnace was set to 680°C. The weight of the die cast product was about 7 kg, and one cycle was 60 s. After casting 10,000 shots, the heat checking on the die surface and the corrosion cracking of the internal cooling circuit were evaluated. Furthermore, evaluation was made also on whether marked soldering or water leakage due to cracking of the internal cooling circuit was generated until casting of 10,000 shorts was completed. The results of the actual machine test are shown in Table 4. In Table 4, the thermal conductivity and the impact value shown in Table 3 are directly inserted.

[0070]

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Table 4

Result of Die Casting Test								
	No.	Heat Checking	Soldering	Wear	Cracking of Water Hole	Cost	Thermal Conductivity	Impact Value
Invention Steel	A01	A	A	A	A	A	28.0	34
	A02	A	A	A	A	A	28.1	32
	A03	A	A	A	A	A	28.2	30
	A04	A	A	A	A	A	28.3	28
	A05	A	A	A	A	A	28.0	36
	A06	A	A	A	A	A	28.6	30
	A07	A	A	A	A	A	29.3	35
	A08	A	A	A	A	A	30.4	35
	A09	A	A	A	A	A	30.4	35
	A10	A	A	A	A	A	30.6	36
	A11	A	A	A	A	A	30.3	34
	A12	A	A	A	A	A	30.7	32
	B01	A	A	A	A	A	30.5	35
	B02	A	A	A	A	A	29.1	34
	B03	A	A	A	A	A	30.5	35
	B04	A	A	A	A	A	29.1	34
	B05	A	A	A	A	A	28.6	33
	B06	A	A	A	A	A	28.2	32
	C01	A	A	A	A	A	30.5	36
	C02	A	A	A	A	A	30.4	35
	C03	A	A	A	A	A	30.6	36
	C04	A	A	A	A	A	30.5	36
	D01	A	A	A	A	A	28.1	35
	D02	A	A	A	A	A	28.3	36
	D03	A	A	A	A	A	28.5	35
	D04	A	A	A	A	A	28.4	36
	E01	A	A	A	A	A	30.6	27
	E02	A	A	A	A	A	30.5	26
	E03	A	A	A	A	A	30.4	21
	E04	A	A	A	A	A	30.5	22
	E05	A	A	A	A	A	30.5	27
	E06	A	A	A	A	A	30.4	27

(continued)

Result of Die Casting Test								
	No.	Heat Checking	Soldering	Wear	Cracking of Water Hole	Cost	Thermal Conductivity	Impact Value
Comparison Steel	A01	B	A	C	A	A	30.6	19
	A02	C	C	A	A	B	27.1	14
	A03	B	C	A	A	A	27.7	30
	A04	C	B	A	A	A	27.9	16
	A05	B	C	A	A	A	25.4	23
	A06	B	A	A	C	A	31.3	17
	A07	B	C	A	A	A	26.5	34
	A08	A	A	C	A	A	29.3	31
	A09	A	A	A	A	B	29.1	25
	A10	C	C	C	C	A	23.8	17

(Evaluation of Actual Machine Test)

[0071] The heat checking, soldering, wear and cracking of water hole were judged with an eye and rated "good" when each was not generated (denoted by "A" in Table 4), rated "slightly bad" when somewhat generated (indicated by "B" in Table 4), and rated "bad" when generated (denoted by "C" in Table 4).

The invention steels exhibited good properties in all items, whereas the comparison steels failed to satisfy the evaluation standard in any of items. This is because the invention steels possessed the component composition above and were assured of high thermal conductivity and high impact value, but the comparison steels did not possess the above-described component composition and were low in the thermal conductivity and/or impact value.

[0072] That is, in the invention steels, the thermal stress was small owing to high thermal conductivity and heat checking hardly occurred. Also, in the case of the invention steels, the high thermal conductivity suppressed overheating of the die, and soldering between the aluminum alloy and the die was greatly reduced. Furthermore, wear by the aluminum alloy injected at a high rate was negligible and responding to the highness of high-temperature strength. In the case of the invention steels, corrosion of the internal cooling circuit was not so much significant, and water leakage due to penetration of a crack originated on the corroded part was not generated.

[0073] On the other hand, it is seen that Comparison Steels A01 to A09 were on an improved trend as compared with JIS SKD61 (Comparison Steel A10) but were inferior to the invention steels. In the steel species where both the thermal conductivity and the impact value were low (Comparison Steels A02, A04 and A10), heat checking was readily generated. Also, in the steel species having a low thermal conductivity (Comparison Steels A02, A03, A05, A07 and A10), soldering was frequently generated. In the steel species low in the high-temperature strength (Comparison Steels A01 and A08), wear was conspicuous. Comparison Steel A09 ensures high die performance, but since the Mo content was high, this material was not recommendable in view of cost or resource saving.

[0074] In particular, Comparison Steel A10 (JIS SKD61) was rated "bad" in all items except for cost, similarly to the evaluation of basic properties. Comparison Steel A10 caused overheating of the die due to its low thermal conductivity and allowed for frequent occurrence of soldering between the aluminum alloy and the die. Also, many heat checks were generated, because the thermal conductivity was low and in turn, the thermal stress was large. The wear by the aluminum alloy injected at a high rate was conspicuous and responding to the lowliness of the high-temperature strength. Furthermore, corrosion of the internal cooling circuit was quite serious, and cracks originated on the corroded part were scattered diffusely.

[0075] The die used in this actual machine test is a die in a large size. The results of this test revealed that despite a large size, the die using the invention steel can have a high impact value and can be high in the thermal conductivity and the high-temperature strength.

[0076] While the present invention is described in the foregoing pages, it should be understood that the present invention is not limited to these embodiments by any means.

[0077] The hot work tool steel of the present invention and the steel product using the same have a high thermal conductivity and a high impact value and therefore, are industrially very valuable for die manufacturers and die users.

Claims

1. A hot work tool steel comprising:

5 $0.20 \leq C \leq 0.50$ mass%,
 $0.01 \leq Si \leq 0.25$ mass%,
 $0.50 < Mn \leq 1.50$ mass%,
 $5.24 < Cr \leq 9.00$ mass%,
 $1.24 < Mo < 2.95$ mass%, and
 10 $0.30 < V < 0.70$ mass%,

optionally further comprising at least one of

 up to 4.00 mass% of W,
 15 up to 3.00 mass% of Co,
 up to 0.100 mass% of Nb,
 up to 0.100 mass% of Ta,
 up to 0.100 mass% of Ti,
 up to 0.100 mass% of Zr,
 20 up to 0.050 mass% of Al,
 up to 0.050 mass% of N,
 up to 1.50 mass% of Cu,
 up to 1.50 mass% of Ni,
 up to 0.0100 mass% of B,
 25 up to 0.500 mass% of S,
 up to 0.200 mass% of Ca,
 up to 0.50 mass% of Se,
 up to 0.100 mass% of Te,
 up to 0.30 mass% of Bi, and
 30 up to 0.50 mass% of Pb,

with the balance being Fe and unavoidable impurities.

2. The hot work tool steel according to claim 1, which comprises at least 0.30 mass% W.

3. The hot work tool steel according to claim 1 or 2, which comprises at least 0.30 mass% Co.

4. The hot work tool steel according to one of claims 1 to 3, which comprises at least one of

40 at least 0.004 mass% of Nb,
 at least 0.004 mass% of Ta,
 at least 0.004 mass% of Ti,
 at least 0.004 mass% of Zr,
 at least 0.004 mass% of Al, and
 45 at least 0.004 mass% of N.

5. The hot work tool steel according to one of claims 1 to 4, which comprises at least one of

50 at least 0.15 mass% of Cu,
 at least 0.15 mass% of Ni, and
 at least 0.0010 mass% of B.

6. The hot work tool steel according to one of claims 1 to 5, which comprises at least one of

55 at least 0.010 mass% of S,
 at least 0.0005 mass% of Ca,
 at least 0.03 mass% of Se,
 at least 0.005 mass% of Te,

at least 0.01 mass% of Bi, and
at least 0.03 mass% of Pb.

5 7. The hot work tool steel according to one of claims 1 to 6, which has a thermal conductivity of 28 W/m·K or more at room temperature.

8. The hot work tool steel according to one of claims 1 to 7, wherein:

10 C is contained in 0.24 to 0.46 or 0.28 to 0.42 mass%,
Si is contained in up to 0.20 or less than 0.10 mass%,
Mn is contained in more than 0.66 or up to 1.20 mass%,
Cr is contained in 5.40 to 7.00 or 5.55 to 6.50 mass%,
Mo is contained in more than 1.37 to 2.80 or 1.50 to 2.50 mass%, and/or
15 V is contained in 0.40 to 0.67 or 0.50 to 0.64 mass%.

9. A steel product comprising the hot work tool steel according to one of claims 1 to 8.

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FIG. 1

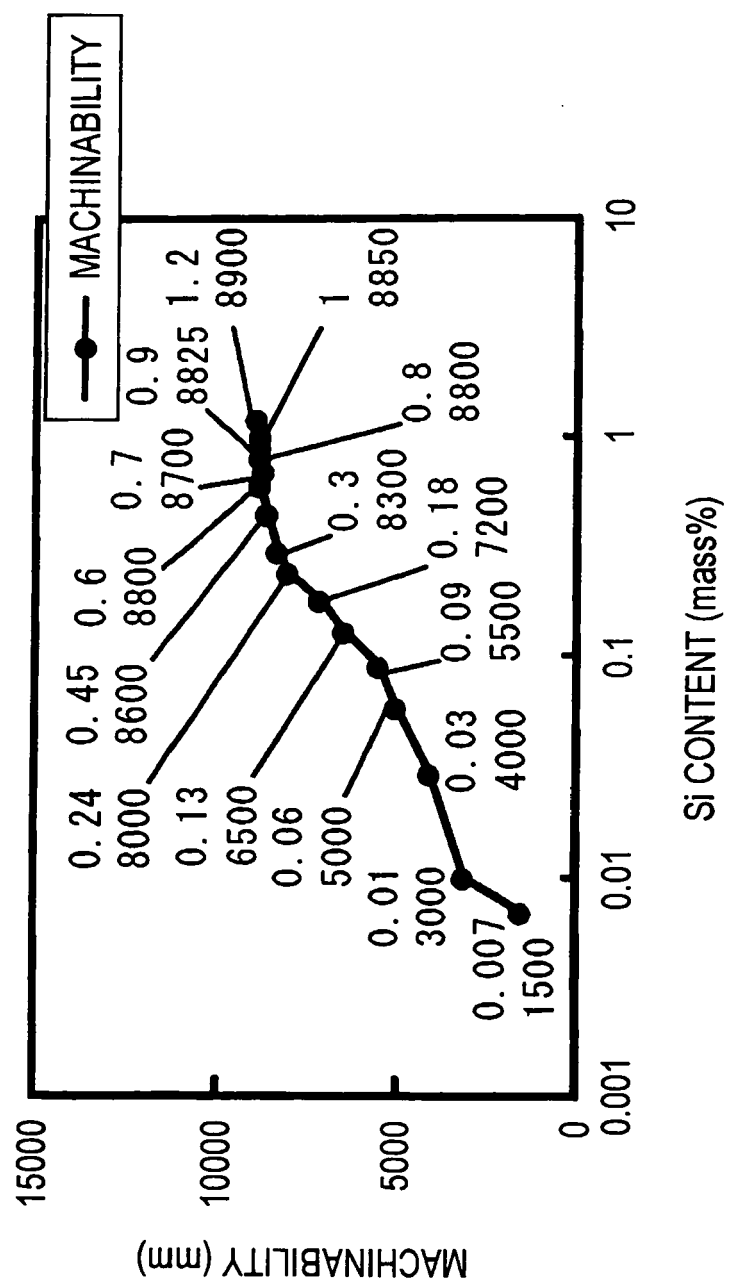


FIG. 2

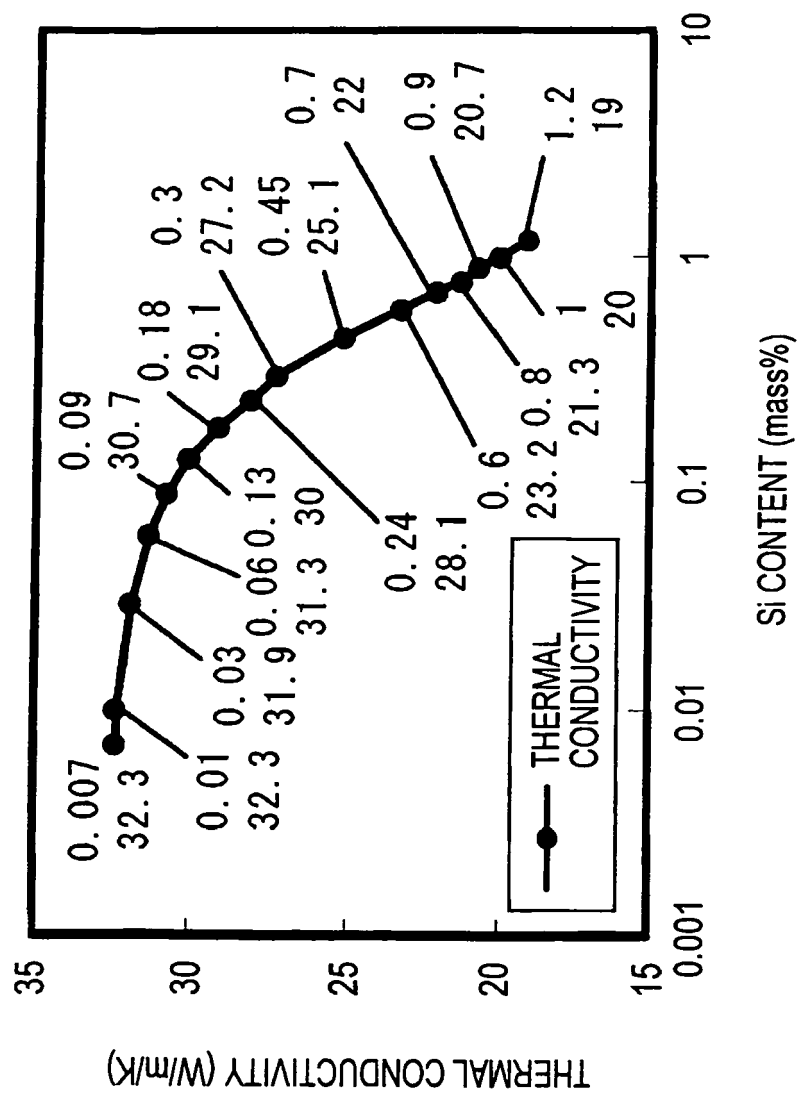


FIG. 3

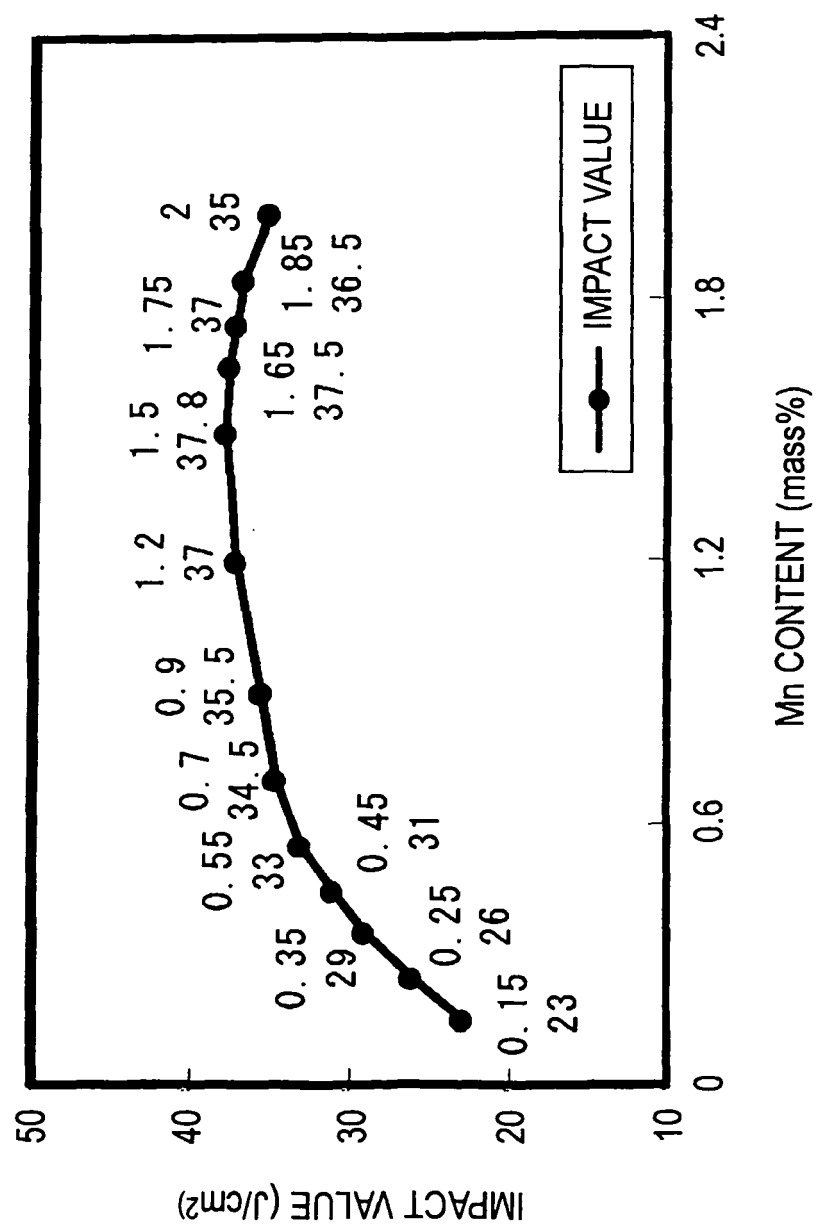


FIG. 4

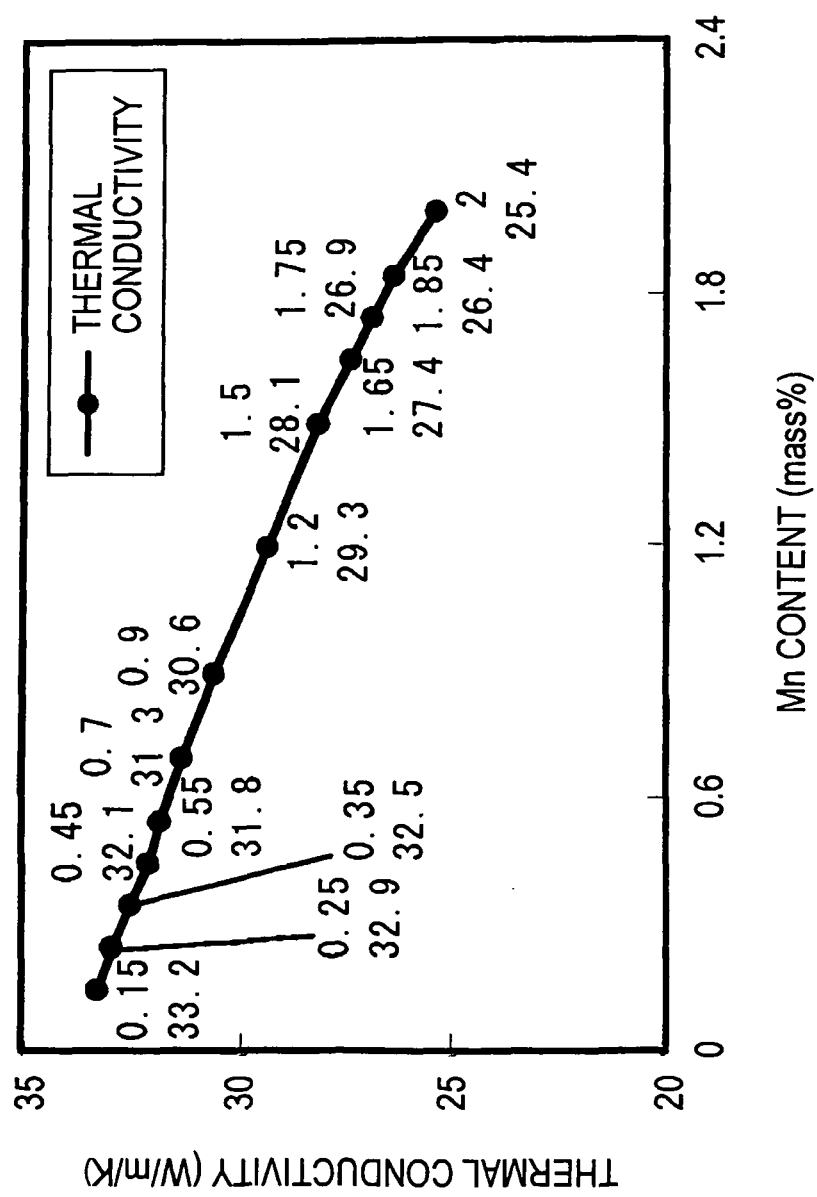


FIG. 5

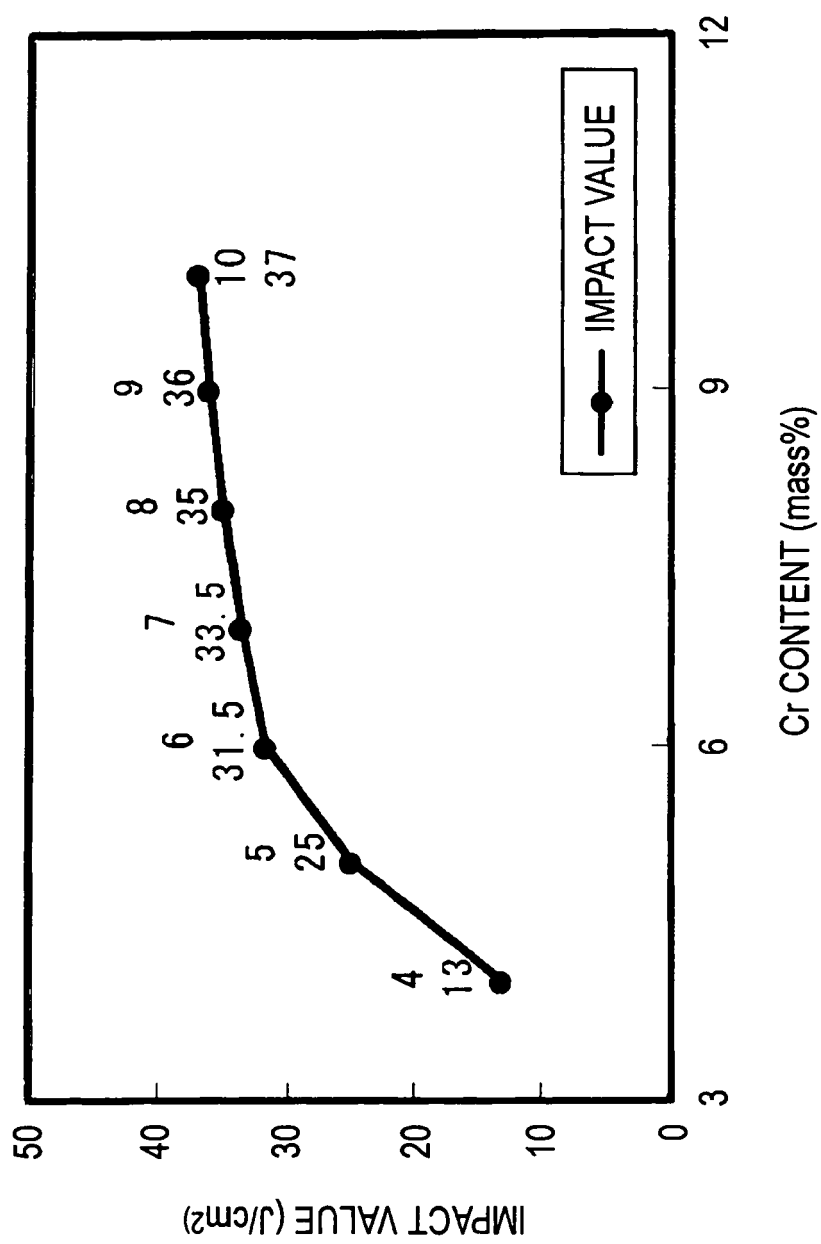


FIG. 6

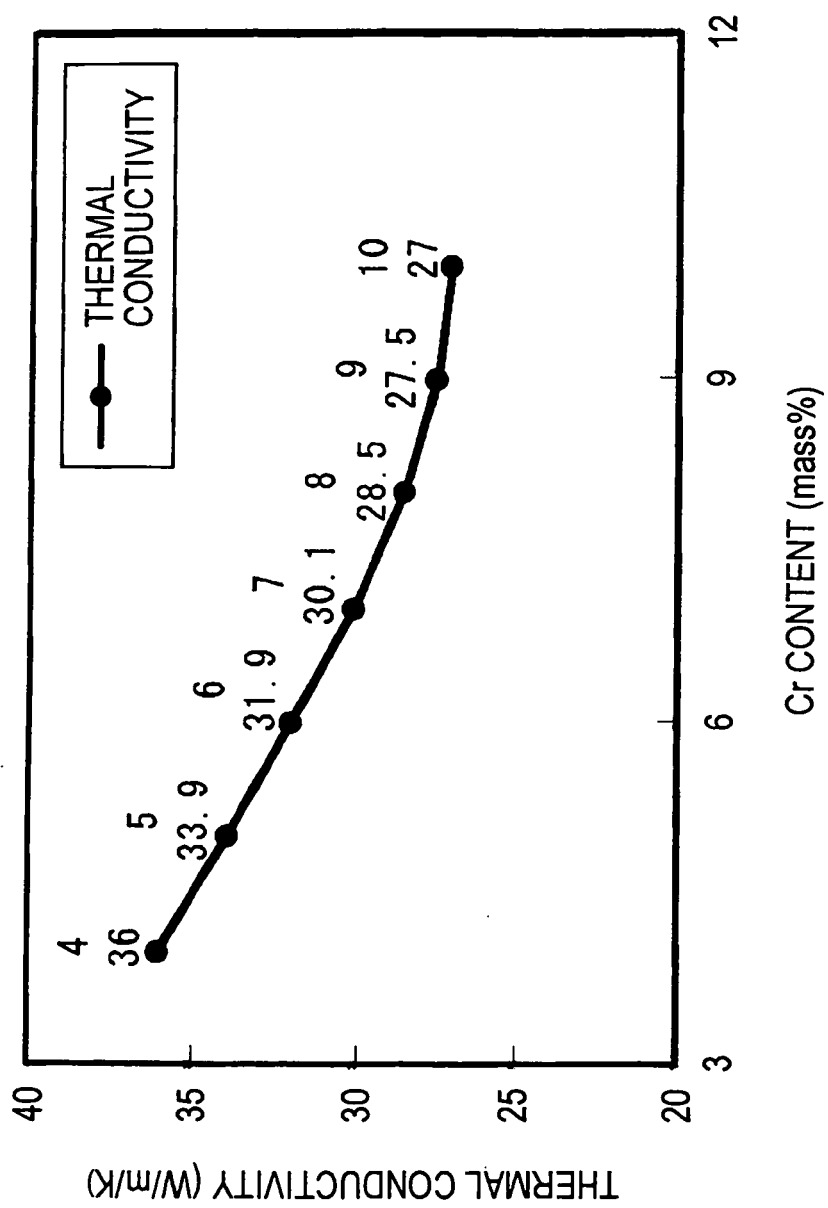


FIG. 7

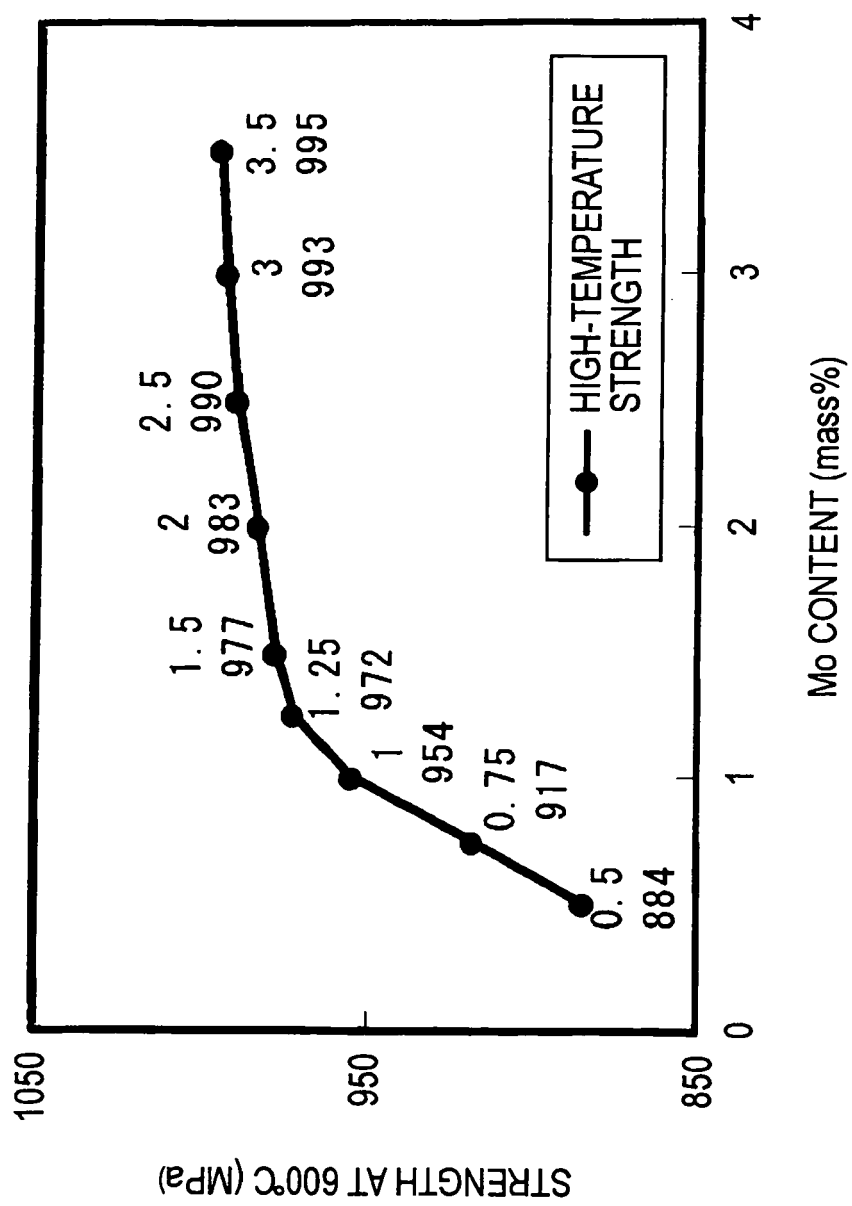
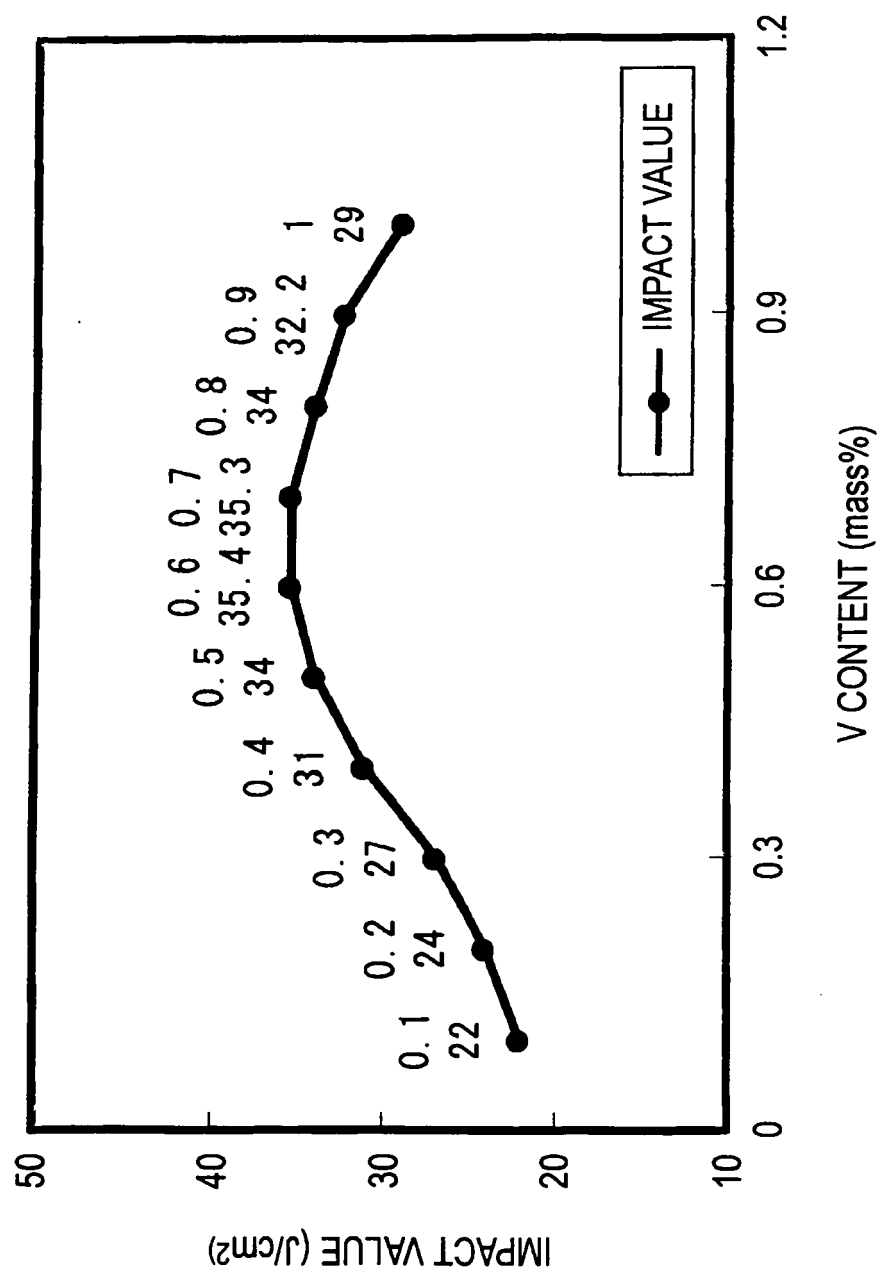


FIG. 8





EUROPEAN SEARCH REPORT

Application Number
EP 10 00 6151

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			C22C
The present search report has been drawn up for all claims			
Place of search Munich		Date of completion of the search 20 October 2010	Examiner Brown, Andrew
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document		T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document	

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EP 10 00 6151

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20-10-2010

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