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(54) **Steel for molding die having excellent thermal conductivity, mirror polishing properties and toughness**

(57) The present invention provides a steel for a molding die, which is excellent in thermal conductivity, mirror polishing properties and toughness. The steel of the invention contains, by mass%, 0.040<C<0.100, 0.03<Si<0.28, 1.11<Mn<1.45, 0.30<Cu<0.77, 0.30<Ni<1.78, 3.23<Cr<9.00, and 0.10<Al<0.50; and further contains at least one of: 0.04<Mo<1.00 and 0.02<V<0.50, with the balance Fe and inevitable impurities.

EP 2 722 406 A1

Description

FIELD OF THE INVENTION

[0001] The present invention relates to a steel for a molding die, which is excellent in thermal conductivity, mirror polishing properties and toughness, and particularly to a steel for a molding die, which is suitable as a material for a plastic molding die.

BACKGROUND OF THE INVENTION

[0002] Various characteristics are required for a material for a die for molding plastic products. In particular, in the case where the plastic products are required to have good appearance with surface smoothness and glossiness, the material for the die is required to have high mirror polishing properties, which makes it possible to finish a molding surface into a smooth and mirror-like surface when the die is constructed.

[0003] Further, in recent years, there has been a strong demand for an improvement in productivity of the plastic products. In order to realize this demand, it is strongly required that the plastic products are molded in "high cycles", that is to say, that the cycle time per cycle of molding is reduced. The material for the die for molding plastic products has been required to satisfy such a demand.

[0004] On the other hand, a demand for a reduction in cost of the die has increasingly become strong, and in order to comply therewith, reductions in material cost and processing cost have been strongly required.
Further, a longer die life can reduce the die cost per product (that is to say, the product cost can be reduced), so that the toughness necessary for realizing a long life of the die has also been required.

[0005] Although there are various plastic products herein, as one of them, there is a frame in four sides of a television screen, which requires seeming beauty. In recent years, such frame has grown in size with a recent growth in size of the television screen, and the die for molding such frame has also necessarily grown in size.
For example, the die for molding such a molded product sometimes becomes large such that the width thereof is more than 1 m and the thickness thereof is tens of centimeters or more.
The material for such a large-sized die must be high in hardenability during quenching.
It is an actual situation that the conventional die materials have not sufficiently complied with such demands.

[0006] In order to finish the die, particularly the molding surface thereof, into a beautiful mirror-like surface, the die material is necessary to have high mirror polishing properties.
For that purpose, it is necessary to decrease the amount of C to be added to the die material.

[0007] When the C amount is large, the amount of carbides formed in a steel material is also increased. The carbides are liable to appear on the surface of the die produced from such a steel material. In this case, when the die surface is mirror polished, the carbides drop off to form holes there as drop-off traces, and when the plastic product is molded, the holes are transferred to the product side to cause a disadvantage of impairing beauty of the product surface, thereby losing the commodity value thereof.

[0008] However, when the C amount is decreased, the hardness necessary for the die is not obtained.

[0009] Accordingly, as means for securing the hardness with the C amount decreased, there have recently been developed materials which allow intermetallic compounds of Cu, Ni and Al to be precipitated and secure the die hardness by precipitation hardening thereof.

[0010] For example, the following Patent Document 1 shows the invention of "Corrosion-Resistant Steel for Plastic Molding Die" and discloses that an intermetallic compound of Cu, Ni and Al is allowed to be precipitated at the time of tempering with the C amount decreased as small as 0.02 to 0.2%, thereby enhancing the hardness of the steel.
However, according to the disclosure of Patent Document 1, Cu and Ni are added in large amounts, and particularly, Al is added in an amount as large as 0.5% or more, thereby allowing the intermetallic compound to be precipitated in large amounts. In this case, the cost is increased by increases in the added amounts of the alloy components, and the toughness becomes insufficient by addition of a large amount of Al.

[0011] Further, the disclosure of Patent Document 1 is silent on enhancement of a cooling performance of the die, which is important for product molding in high cycles (reduction in cycle time), and a countermeasure therefor is not particularly taken.
Specifically, the content of Si which plays an important role at the time of cooling the die is large (although described to be 1.5% or less in the claims, the lower limit thereof is 0.3% in the examples, and no content lower than this limit is disclosed therein).
When Si is contained in an amount as large as 0.3% or more, the cooling performance of the die after injection becomes insufficient, and it is difficult to realize the molding in higher cycles than ever before.

[0012] Furthermore, the following Patent Document 2 shows the invention of "Steel for High-Strength Die Excellent in Machinability" and discloses a steel for a die for molding a plastic product and the like, in which the hardness of the steel is enhanced by a precipitation effect of Cu and precipitation of an intermetallic compound ofNi and Al, with the C amount decreased as small as 0.005 to 0.1 %.

[0013] However, according to the disclosure of Patent Document 2, the intermetallic compound of Ni and Al is also allowed to be precipitated in large amounts.

Specifically, in the disclosure of Patent Document 2, Ni is described to be 4.0% or less and Al is described to be 0.1 to 2.0% in the claims. However, the lower limit of A1 is 0.74% in the examples, and in all of the examples, the Al amount is larger than this limit. Further, also for Ni, the lower limit thereof is 1.78% in the examples, and in all of the examples, Ni is added in larger amounts than this limit.

Furthermore, also for Cu, the lower limit thereof is described to be 3.5% or less in the claims. However, the lower limit thereof in the examples is 0.77%, and in all of the examples, the Cu amount is larger than this limit.

[0014] In addition, the disclosure of Patent Document 2 is also silent on enhancement of the cooling performance of the die, which becomes important for product molding in high cycles, and a countermeasure therefor is not particularly taken.

[0015] Specifically, also in the disclosure of Patent Document 2, a large amount of Si is contained (although described to be 1.5% or less in the claims, the lower limit thereof is 0.28% in the examples, and no content lower than this limit is disclosed therein).

[Patent Document 1] JP-A-11-140591
[Patent Document 2] JP-A-2000-297353

SUMMARY OF THE INVENTION

[0016] Against the background of the circumstances as described above, the invention has been made for the purpose of providing a steel for a molding die, which is high in thermal conductivity, excellent in mirror polishing properties and also excellent in toughness.

[0017] Namely, the present invention provides the followings.

1. A steel for a molding die, the steel comprising, by mass%,

$$0.040<C<0.100,$$

$$0.03<Si<0.28,$$

$$1.11<Mn<1.45,$$

$$0.30<Cu<0.77,$$

$$0.30<Ni<1.78,$$

$$3.23<Cr<9.00,$$

and

$$0.10<Al<0.50;$$

and

[0018] further comprising at least one of:

$$0.04<Mo<1.00$$

and

$$0.02<V<0.50,$$

with the balance Fe and inevitable impurities.

[0019] 2. The steel for a molding die according to item 1 above, further comprising, by mass%, at least one of:

$$0.30<W\leq 4.00$$

and

$$0.30<Co\leq 3.00.$$

[0020] 3. The steel for a molding die according to item 1 or 2 above, further comprising, by mass%, at least one of:

$$0.004<Nb\leq 0.100,$$

$$0.004<Ta\leq 0.100,$$

$$0.004<Ti\leq 0.100$$

and

$$0.004<Zr\leq 0.100$$

[0021] 4. The steel for a molding die according to any one of items 1 to 3 above, further comprising, by mass%, $0.0001<B<0.0050$.

[0022] 5. The steel for a molding die according to any one of items 1 to 4 above, further comprising, by mass%, at least one of:

$$0.003<S\leq 0.050,$$

$$0.0005<Ca\leq 0.2000,$$

$$0.03<Se\leq 0.50,$$

$$0.005<Te\leq 0.100,$$

$$0.01<Bi\leq 0.30$$

and

$$0.03<Pb\leq 0.50.$$

[0023] 6. The steel for a molding die according to any one of items 1 to 5 above, which has an average hardness at room temperature within the range of 35 to 45 HRC.

[0024] 7. The steel for a molding die according to item 6 above, which has a thermal conductivity measured by a laser flash method at 200°C of 26 W/(m·K) or more.

[0025] 8. The steel for a molding die according to item 6 or 7 above, which satisfies, by mass%, 5.00<Mn+Cr+0.5Ni<6.20.

[0026] 9. The steel for a molding die according to any one of items 6 to 8 above, which satisfies, by mass%, 0.19<0.5Mo+V<0.45.

[0027] The invention is characterized by that in a steel in which the hardness is secured by aging precipitation of Cu, Ni and A1 with the added amount of C decreased, the added amounts of Cu, Ni and Al are decreased with exertion of secondary hardening based on addition of Mo and V.
The present inventors have examined the added amounts of Cu, Ni and Al necessary for obtaining the steel having a predetermined hardness. As a result, it has been found that even when the added amounts of Cu, Ni and Al are decreased more than those of a conventional steel, the desired hardness such as 35 to 45 HRC can be sufficiently realized.
The invention has been made under such a finding.
Thus, when the added amounts of Cu, Ni and Al can be decreased, the material cost can be reduced, and machinability of the steel is improved, which makes it possible to reduce the processing cost.

[0028] In particular, the invention is characterized by that Al as an element for forming an intermetallic compound is restricted as low as less than 0.50%.
When a certain amount or more of Al is added, the toughness is decreased by the aging precipitation of the intermetallic compound. Further, Al not used for the aging precipitation is solid-dissolved into a matrix to decrease the toughness of the matrix itself.
In the case where the toughness of the steel is decreased, the die constructed by using the steel becomes liable to be cracked.
In the invention, therefore, the toughness of the steel is secured high by restricting the added amount of Al small.

[0029] The invention is also characterized by that the mirror polishing properties of the steel can be enhanced by decreasing the added amount ofNi as an element which forms the intermetallic compound together with A1.
Ni is an element which is easily segregated in a stripe form in the steel, and when segregation of Ni occurs in such a form, Ni-rich portions and Ni-poor portions are alternately generated in the steel.
In this case, the Ni-rich portions are different from the Ni-poor portions in mechanical properties such as hardness and toughness, so that striped (streaky) unevenness occurs in the steel at the time when mirror polishing is performed.
Accordingly, when the die is constructed by such a steel, this striped unevenness is transferred to a molded product such as a plastic product, which greatly impairs appearance of the product, thereby losing the commodity value thereof.
In the invention, the occurrence of such a problem is prevented by restricting the upper limit of the added amount of Ni low.
The same can be said for Cu. Similarly to Ni, Cu is easily segregated. Accordingly, as a means for preventing the occurrence of the striped unevenness at the time when mirror polishing is performed, it is effective to restrict the upper limit of the added amount of Cu low. In the invention, Ni and Cu are decreased more than those of a conventional steel containing Ni and Cu, so that the striped unevenness is difficult to occur at the time when mirror polishing is performed.

[0030] The invention is further greatly characterized by that the added amount of Si is decreased, thereby securing the thermal conductivity of the steel high.
When the die for injection molding is constructed by using the steel having high thermal conductivity (high thermal conductive performance), a cooling performance of the die is enhanced to improve heat dissipation of the die at the time of injection molding, thereby being able to reduce the time per cycle of molding. That is to say, product molding by injection molding can be performed in high cycles, whereby productivity can be increased.

[0031] Incidentally, the steel of the invention is particularly suitable for a material for a die for forming plastic products, but is also suitable for a material for a die other than the die for plastic molding, for example, a material for a die for producing (molding) rubber products.

BRIEF DESCRIPTION OF THE DRAWINGS

[0032]

Fig. 1 is a graph showing the relationship between the tool wear amount and the Si amount.
Fig. 2 is a graph showing the relationship between the thermal conductivity and the Si amount.

Fig. 3 is a graph showing the relationship between the tempering hardness and the Al amount.
Fig. 4 is a graph showing the relationship between the impact value and the Al amount.
Fig. 5 is a graph showing the relationship between Mn+Cr+0.5Ni and the impact value.
Fig. 6 is a graph showing the relationship between Mn+Cr+0.5Ni and the thermal conductivity.
Fig. 7 is a graph showing the relationship between 0.5Mo+V and the HRC hardness.
Fig. 8 is a graph showing the relationship between 0.5Mo+V and the impact value.
Fig. 9 is an illustration for illustrating a method of a test which simulates water cooling hole cracking.
Fig. 10 is a graph showing the results of a test which simulates water cooling hole cracking.
Fig. 11 is a graph showing the relationship between the tempering hardness and the tempering temperature.

DETAILED DESCRIPTION OF THE INVENTION

[0033] Reasons for restriction of the chemical compositions and the like of the invention will be described in detail below. Herein, each numerical value associated with inequality sign (or inequality sign with equality sign) and each element means the amount of the element in terms of % by mass. For example, $0.040<C<0.100$ indicates that the amount of C is more than 0.040% by mass and less than 0.100% by mass. Same shall apply to the others.

[Chemical Components of item 1 above]

C: $0.040<C<0.100$

[0034] When $C\leq0.040$, it is difficult to obtain a hardness of 35 HRC or more which is necessary for securing high mirror surface properties, particularly when the tempering temperature is high. When $C\geq0.100$, the corrosion resistance is decreased, and weldability is also deteriorated. The preferred range thereof is $0.060<C<0.095$ which is excellent in the balance of these characteristics.

Si: $0.03<Si<0.28$

[0035] When $Si\leq0.03$, the machinability is significantly deteriorated. When $Si\geq0.28$, the thermal conductivity is largely decreased. The preferred range is $0.05<Si<0.27$ which is excellent in the balance of the machinability and the thermal conductivity.
Fig. 1 and Table 1 show the machinability after 0.078C-1.19Mn-0.72Cu-1.21Ni-4.02Cr-0.40Mo-0.10V-0.40Al-Si steel was soaked at 900°C for 3 hours and thereafter quenched, followed by tempering at 510°C for 5 hours, with respect to the Si amount. A material for evaluation of the machinability had a hardness of 39 to 42 HRC, and the shape thereof was a square bar of 55 mm × 55 mm × 200 mm. The time point when the major flank maximum wear amount of a cutting tool reached 300 μm was judged as the lifetime (machinability). The longer cutting distance is preferred because of better cutting.
When $Si\leq0.03$, the cutting distance is extremely short. In order to stably suppress wear of the cutting tool, $Si>0.03$ is required. When $Si>0.05$, wear can be more stably suppressed.

Table 1

Si	Cutting Distance
0.01	365
0.02	436
0.03	751
0.04	1318
0.05	2080
0.06	3004
0.09	4981
0.13	7006
0.17	8191
0.21	9512

(continued)

Si	Cutting Distance
0.23	9971
0.27	10996
0.28	11189
0.29	11378
0.31	11582
0.33	11983
0.38	12179
0.45	12606

[0036] Fig. 2 and Table 2 show the thermal conductivity at room temperature after the steels of the invention were soaked at 900°C for 3 hours and thereafter quenched, followed by tempering at 510°C for 5 hours, with respect to the Si amount. The steel materials were the following three kinds:

Steel S1:

[0037] 0.077C-1.19Mn-0.69Cu-1.21Ni-4.00Cr-0.39Mo-0.11V-0.41Al-Si steel

Steel S2:

[0038] 0.068C-1.20Mn-0.70Cu-1.19Ni-5.13Cr-0.40Mo-0.10V-0.39Al-Si steel

Steel S3:

[0039] 0.058C-1.20Mn-0.71Cu-1.22Ni-7.93Cr-0.40Mo-0.11V-0.41Al-Si steel

Table 2

Relationship between Si Amount and Thermal Conductivity			
Si (mass%)	Steel S1 (W/(m·K))	Steel S2 (W/(m·K))	Steel S3 (W/(m·K))
0.01	35.3	33.6	29.8
0.02	35.3	33.6	29.8
0.03	35.2	33.5	29.7
0.04	35.1	33.4	29.7
0.05	35.1	33.4	29.7
0.06	35	33.3	29.7
0.09	35	33.3	29.6
0.13	34.7	32.8	29.6
0.17	34.3	32.3	29.1
0.21	33.5	31.6	28.2
0.23	32.8	30.7	27.6
0.27	31.3	29.8	26.6
0.28	30.8	29.3	26
0.29	30.4	29.2	25.8
0.31	29.9	28.7	25.3

(continued)

Relationship between Si Amount and Thermal Conductivity			
Si (mass%)	Steel S1 (W/(m·K))	Steel S2 (W/(m·K))	Steel S3 (W/(m·K))
0.33	29.5	28.1	24.9
0.38	28.8	27.4	24.3
0.45	27.9	26.4	23.4

[0040] A material for evaluation of the thermal conductivity had a hardness of 39 to 42 HRC, and the shape thereof was a small disk of 10 mm diameter × 2 mm. The thermal conductivity was measured by a laser flash method at 200°C. That is to say, a test specimen at room temperature was perpendicularly irradiated with a laser light emitted from a laser oscillator, and the amount of heat radiated from a back surface of the test specimen at this time was measured with an infrared detector to determine specific heat and the thermal diffusivity. Finally, the thermal conductivity (= specific heat × thermal diffusivity × density) was calculated.

[0041] The higher thermal conductivity is preferred, because the die formed is more excellent in cooling performance. Although the thermal conductivity varies according to the components of the steel material, a tendency of an increase in thermal conductivity with a decrease in Si is the same.
In all steel grade systems, an inflection point of an increase in thermal conductivity appeared in Si<0.28. That is to say, in order to keep the thermal conductivity of that component system high, Si<0.28 is necessary. When Si<0.27, high thermal conductivity is more stably obtained. When Si≤0.05, the thermal conductivity shows a tendency of saturation.

[0042] A measure for judging whether the die formed is high in cooling performance or not is whether the thermal conductivity of the steel material at 200°C is 26 W/(m·K) or more or not. The reason for paying attention to 200°C is that during an injection molding process, the temperature of a die surface is within the range of 30 to 300°C, particularly around 200°C, in many cases. In the invention, the steel material having a thermal conductivity of 28 W/(m·K) or more at 200°C is preferred. Further, even when the thermal conductivity is 26 W/(m·K) or more, the cooling performance is considerably high. In a component system highly alloyed in terms of the strength, the corrosion resistance and the like, the thermal conductivity becomes somewhat low. Nevertheless, it is preferred that the steel material has a thermal conductivity of 26 W/(m·K) or more at 200°C.

[0043] In plastic injection molding which is an application field of the invention, there is a strong need for improvement of productivity. For that purpose, it is necessary to decrease the solidification time per product. That is to say, the die must be rapidly cooled. It has therefore been tried to mount a proper cooling circuit in the inside of the die. However, from the viewpoint of a die structure, it is sometimes impossible to mount cooling holes. Further, when the cooling holes are put too close to a die surface, it becomes a cause for early cracking of the die.

[0044] On the other hand, there is also a try to mount the cooling circuit by lamination (sintering or junction) of powder or plates on a place on which it has hitherto been impossible to mount the cooling holes, thereby dramatically improving cooling power of the die. However, special equipment becomes necessary for production thereof, and it is also expensive. Further, when the cooling holes are put too close to the die surface, it becomes a cause for early cracking of the die.

[0045] According to the invention, the problems described above are solved, and the die can be efficiently cooled. That is to say, by increasing the thermal conductivity of the die, the sufficient cooling effect can be obtained without putting the cooling holes extremely close to the die surface. For this reason, the problem of early cracking of the die is hard to occur. Further, no special equipment is necessary for production of the die, and it is possible to produce the die in the same process as conventionally used. It is an outstanding characteristic of the invention to balance the thermal conductivity with the other characteristics as described above.

[0046] As a matter of course, when the steel of the invention is applied to the method of "producing the die by lamination (sintering or junction) of powder or plates", the greater cooling effect is obtained.

Mn: 1.11<Mn<1.45

[0047] When Mn≤1.11, hardenability during quenching is insufficient. When Mn≥1.45, the thermal conductivity is significantly decreased. Further, Mn is easily segregated at the time of coagulation, and significant segmentation has adverse effects on the mirror polishing properties in the case where the die is formed of the steel. The preferred range thereof is 1.15<Mn<1.39 which is excellent in the balance of the hardenability during quenching, the thermal conductivity and the mirror polishing properties.

Cu: 0.30<Cu<0.77

[0048] When Cu≤0.30, an effect of increasing the strength due to aging precipitation of Cu is small. When Cu≥0.77, cracking is liable to occur at the time of hot working. The preferred range thereof is 0.40<Cu<0.75 which is excellent in the balance of an increase in strength and the hot workability.

[0049] In low-C steel, it is difficult to obtain sufficient strength when the tempering temperature is low. This is because the degree of reinforcement due to secondary precipitation of a carbide is small. The aging precipitation of Cu is an effective means for securing the strength of low-C steel. Conventional steels utilizing the aging precipitation of Cu contain 1 to 3% of Cu in many cases. In the invention, the sufficient strength can be obtained by a combination of the secondary precipitation of the carbide with the aging precipitation of the intermetallic compound (composed of Ni and Al).

Ni: 0.30<Ni<1.78

[0050] When Ni≤0.30, an effect of improving the hardenability during quenching is small. When Ni≥1.78, the material cost is extremely increased. Further, Ni is easily segregated at the time of coagulation, and significant segmentation has adverse effects on the mirror polishing properties in the case where the die is formed of the steel. The preferred range thereof is 0.39<Ni<1.55 which is excellent in the balance of the hardenability during quenching, the cost and the mirror polishing properties.

Cr: 3.23<Cr<9.00

[0051] When Cr≤3.23, an effect of improving the corrosion resistance is small. When Cr≥9.00, the thermal conductivity is significantly decreased. The preferred range thereof is 3.50<Cr<8.60 which is excellent in the balance of the corrosion resistance and the thermal conductivity. When the corrosion resistance is important, the preferred range is 4.50<Cr<8.60, although the thermal conductivity is somewhat decreased.

Mo: 0.04<Mo<1.00

[0052] When Mo≤0.04, it is difficult to obtain a necessary hardness of 35 HRC or more, particularly when the tempering temperature is high. When Mo≥1.00, the fracture toughness value is significantly decreased. The preferred range thereof is 0.10<Mo<0.90 which is excellent in the balance of the hardness and the fracture toughness value.

V: 0.02<V<0.50

[0053] When V≤0.02, it is difficult to obtain a hardness of 35 HRC or more which is necessary for securing the high mirror surface properties, particularly when the tempering temperature is high. When V≥0.50, the impact value and the mechanical fatigue strength are significantly decreased. The preferred range thereof is 0.05<V<0.40 which is excellent in the balance of the hardness and the impact value.

Al: 0.10<Al<0.50

[0054] When Al<0.10, an effect of increasing the strength due to aging precipitation of the intermetallic compound composed of Ni and Al is small. When Al>0.50, the impact value is significantly decreased. The preferred range thereof is 0.14<Al<0.47 which is excellent in the balance of the hardness and the toughness.

[0055] Fig. 3 shows the HRC hardness at room temperature after 0.080C-0.19Si-1.23Mn-0.72Cu-1.20Ni-4.OlCr-0.38Mo-0.12V-Al steel was soaked at 900°C for 3 hours and thereafter quenched, followed by tempering at 525°C for 5 hours, with respect to the Al amount. In order to obtain a hardness of 35 HRC or more which is necessary for securing the high mirror surface properties, it is necessary to be Al>0.10, and when Al>0.14, the hardness is more stably obtained.

[0056] In low-C steel, it is difficult to obtain the sufficient strength when the tempering temperature is low. This is because the degree of reinforcement due to the secondary precipitation of the carbide is small, and the aging precipitation of the intermetallic compound of Ni and Al is an effective means for securing the strength of low-C steel.

[0057] Fig. 4 shows the impact value evaluated by performing a Charpy impact test using a JIS No. 3 impact test specimen of 10 mm × 10 mm × 55 mm, after a square bar of 11 mm × 11 mm × 55 mm of 0.080C-0.19Si-1.23Mn-0.72Cu-1.20Ni-4.01Cr-0.38Mo-0.12V-Al steel was soaked at 900°C for 3 hours and thereafter quenched by rapid cooling, followed by tempering at 500 to 550°C for 5 hours to obtain a hardness of 39 to 42 HRC, with respect to the Al amount. The test temperature was room temperature. The larger impact value is preferred because of higher cracking resistance.

[0058] In the steel (containing Al of about 1 %) from which the intermetallic compound composed of Ni and Al is precipitated, the low impact value poses a problem. In the steel of the invention, in order to solve this problem, it has been studied to decrease Al. The impact value is increased by a decrease in Al, and an effect thereof becomes obvious in Al<0.5. When Al<0.47, a high impact value is more stably obtained.

[0059] In the invention, the hardness is effectively obtained by utilizing 3 types of dispersion strengthening mechanisms, specifically, (1) the secondary precipitation of the carbide mainly composed of Mo or V, (2) the aging precipitation of Cu and (3) the aging precipitation of the intermetallic compound composed of Ni and Al. Conventional steels utilizing intermetallic compounds contain 2 to 3% of Ni and 1 to 2% of Al in many cases. In the invention, the high impact value is achieved while effectively obtaining the hardness by a combination of (1) with (2) without using Ni and Al in such large amounts.

[Chemical Components of item 2 above]

[0060] The steel of the invention contains C in small amounts, so that it is difficult to secure the strength depending on the tempering temperature. In such a case, W and/or Co is selectively added to maintain the strength. W increases the strength by precipitation of a carbide. Co increases the strength by solid dissolving thereof into a matrix, and at the same time, contributes to precipitation hardening through changes in carbide morphology. Specifically, at least one of $0.30<W\leq4.00$ and $0.30<Co\leq3.00$ is allowed to be contained.

[0061] For both the elements, addition thereof in amounts exceeding the predetermined amounts causes saturation of the characteristics and an increase in cost. The preferred ranges thereof are $0.40\leq W\leq3.00$ and $0.40\leq Co\leq2.00$, respectively.

[Chemical Components of item 3 above]

[0062] In the steel of the invention, there are not so many dispersed particles which suppress growth of austenitic grains at the time of quenching. For this reason, when the quenching heating temperature is raised or the quenching heating time is lengthened by an unexpected trouble of equipment or the like, there is a concern that various characteristics are deteriorated by grain coarsening. For such an occasion, Nb, Ta, Ti and/or Zr are selectively added, and coarsening of the austenitic grains can be suppressed by fine precipitates formed by these elements. Specifically, at least one of $0.004<Nb\leq0.100$, $0.004<Ta\leq0.100$, $0.004<Ti\leq0.100$ and $0.004<Zr\leq0.100$ is allowed to be contained.

[0063] For all the elements, addition thereof in amounts exceeding the predetermined amounts excessively forms carbides, nitrides or oxides, which causes deterioration of the impact value or the mirror polishing properties.

[Chemical Component of item 4 above]

[0064] In recent years, the die size tends to become large with an increase in size and integration of parts. It is difficult to cool a large-sized die. For this reason, when the large-sized die of a steel material having low hardenability during quenching is quenched, ferrite, pearlite or coarse bainite is precipitated during quenching to deteriorate various characteristics. The steel of the invention has considerably high hardenability during quenching, so that such a concern is less likely present. However, in case an extremely large die is treated by a quenching method in which the cooling intensity is weak, the hardenability during quenching can be further enhanced by adding B.
Specifically, $0.0001<B\leq0.0050$ is allowed to be contained.

[0065] Incidentally, when B forms BN, the effect of improving the hardenability during quenching is lost. It is therefore necessary to allow B to be independently present in the steel. Specifically, a nitride is allowed to be formed with an element having a stronger affinity with N than B to avoid the binding ofB and N. Examples of such elements include the respective elements enumerated in item 3 above. The elements enumerated in item 3 above have an effect of fixing N, even when present at an impurity level. However, depending on the N amount which can be contained in a manufacturing process, they are preferably added within the ranges defined in item 3 above.

[Chemical Components of item 5 above]

[0066] The steel of the invention is somewhat lower in the Si amount than a steel (Si>0.4) having extremely excellent machinability. For this reason, there is a concern that it becomes difficult to perform machine processing into a die configuration or to make holes. In such a case, S, Ca, Se, Te, Bi and/or Pb are selectively added to improve the machinability.
Specifically, at least one of $0.003<S\leq0.050$, $0.0005<Ca\leq0.2000$, $0.03<Se\leq0.50$, $0.005<Te\leq0.100$, $0.01<Bi\leq0.30$ and $0.03<Pb\leq0.50$ is allowed to be contained.
For all the elements, addition thereof in amounts exceeding the predetermined amounts causes saturation of the machinability, deterioration of the hot workability (in producing a die material) and deterioration of the impact value or the mirror polishing properties.

[Chemical Components of item 8 above]

[0067] In the invention, when the added amounts of Mn, Cr and Ni are the lower limits thereof, Mn+Cr+0.5Ni=4.52 stands. However, when the hardenability during quenching is particularly required, Mn+Cr+0.5Ni>5.00 is adopted, thereby being able to further reduce a risk that ferrite, pearlite or coarse bainite is precipitated during quenching.
[0068] Further, in the invention, when these components are added in the upper limit amounts, Mn+Cr+0.5Ni=11.32 stands. However, when the thermal conductivity is particularly required, Mn+Cr+0.5Ni<6.20 is adopted. The range particularly excellent in the balance of the hardenability during quenching and the thermal conductivity is 5.00<Mn+Cr+0.5Ni<6.20, and the more preferred range is 5.20<Mn+Cr+0.5Ni<6.05. Within this range, a proper hardened structure can be stably obtained, and the thermal conductivity at 200°C becomes 28 W/(m·K) or more.
[0069] Fig. 5 shows the impact value (2 mm U-notch) of a Charpy impact test at room temperature in a state where the steels of the invention were soaked at 900°C for 3 hours and thereafter quenched, followed by tempering at 520°C for 5 hours to obtain a hardness of 39 to 41 HRC, with respect to the Mn+Cr+0.5Ni amount. As the materials, there are used all the following 22 steel grades:

Steel L:

[0070] 0.072C-0.22Si-0.72Cu-0.40Mo-0.11V-0.40Al-3.24Cr-1.12Mn-0.31Ni steel,

Steel M:

[0071] 0.074C-0.20Si-0.71Cu-0.38Mo-0.12V-0.41Al---8.99Cr-1.44Mn-1.77Ni steel,

R1 system: 0.072C-0.21Si-0.68Cu-0.40Mo-0.10V-0.40Al---3.52Cr-Mn-Ni steel,
R2 system: 0.072C-0.20Si-0.70Cu-0.41Mo-0.09V-0.40A1---4.03Cr-Mn-Ni steel,
R3 system: 0.073C-0.20Si-0.72Cu-0.41Mo-0.10V-0.38Al---5.49Cr-Mn-Ni steel, and
R4 system: 0.073C-0.21Si-0.70Cu-0.41Mo-0.10V-0.39A1---4.03Cr-Mn-Ni steel

Steel L has a composition in which Mn, Cr and Ni are added in the lower limit amounts, and steel M has a composition in which Mn, Cr and Ni are added in the upper limit amounts. Further, steel R1 to R4 systems consist of 20 steel grades in which Mn and Ni are arbitrarily added within the range defined in item 8 above. Quenching is performed herein as a process in which a large section die is simulated. That is to say, the cooling rate is 15°C/min from 900°C to 600°C, and 3°C/min from 600°C to room temperature.
[0072] The material which provides a high impact value even by such slow quenching is excellent in hardenability during quenching, and can be used also for a large die without anxiety.
As can be seen from Fig. 5, steel L also has a relatively high compact value of 21 J/cm^2, which shows that the component systems of the steels of the invention are excellent in hardenability during quenching. Among commercially available steel materials, there are many steels having an impact value of 15 J/cm^2 or less. Paying attention to Mn+Cr+0.5Ni>5.00 herein, an increase in the impact value is observed, and it is apparent that this is a region particularly excellent in hardenability during quenching. When Mn+Cr+0.5Ni>5.20, the high thermal conductivity (appropriately 25 J/cm^2 or more) is further stably obtained.
[0073] Fig. 6 shows the relationship between the thermal conductivity at 200°C and Mn+Cr+0.5Ni. As the materials, there are used the same 22 steel grades as in Fig. 5. In general, the thermal conductivity decreases with an increase of alloy elements. Steel M also has a relatively high thermal conductivity of 24.4 W/(m·K), which shows that the component systems of the steels of the invention are excellent in thermal conductivity. Among commercially available steel materials, there are many steels having a thermal conductivity of 24 W/(m·K) or less. Paying attention to Mn+Cr+0.5Ni<6.20 herein, 28 W/(m·K) or more is observed, and it is apparent that this is a region of particularly high thermal conductivity. When Mn+Cr+0.5Ni<6.05, the high thermal conductivity is further stably obtained.
On the other hand, depending on needs for the corrosion resistance, nitriding and the like, when Cr>4.50, Mn+Cr+0.5Ni≥6.20 may be adopted. The hardenability during quenching in that case can be said to be somewhat excessive. However, the impact value is increased, and moreover, a larger die can also be quenched without anxiety. However, the thermal conductivity thereof is lower than that of the steel in which Mn+Cr+0.5Ni<6.20. Nevertheless, when the thermal conductivity is 26 W/(m·K) or more, cooling power as the die is sufficiently large. That is to say, for Mn+Cr+0.5Ni>6.20, there is selected a component system in which the thermal conductivity becomes 26 W/(m·K) or more at 200°C.

[Chemical Components of item 9 above]

[0074] In the invention, 0.5Mo+V=0.06 stands in composition in which Mo and V are added in the lower limit amounts. However, in order to stably obtain the hardness, 0.5Mo+V>0.19 is adopted, which makes it possible to more easily obtain a hardness of 35 HRC or more. Further, in the invention, 0.5Mo+V=0.98 stands in composition in which Mo and V are added in the upper limit amounts. However, when the fracture toughness value, the impact value or the mechanical fatigue strength is particularly required, 0.5Mo+V<0.45 is adopted. The range which is particularly excellent in the balance of the above-mentioned characteristics is 0.19<0.5Mo+V<0.45. The more preferred range is 0.22<0.5Mo+V<0.42. Within this range, a hardness of 35 HRC or more can be stably obtained, and there is no significant decrease in fracture toughness value, impact value or mechanical fatigue strength.
On the other hand, tempering is sometimes necessarily performed at high temperature in an after process such as nitriding. In such a case, 0.5Mo+V≥0.45 may be adopted.
[0075] Fig. 7 shows the HRC hardness at room temperature after the steels of the invention were soaked at 900°C for 3 hours and thereafter quenched, followed by tempering at 535°C for 5 hours, with respect to the 0.5Mo+V amount. As the materials, there are used all the following 22 steel grades:

Steel L2:

[0076] 0.072C-0.19Si-1.21Mn-0.70Cu-1.18Ni-4.01Cr-0.39Al---0.05Mo-0.03V steel,

Steel M2:

[0077] 0.073C-0.20Si-1.20Mn-0.71Cu-1.17Ni-4.00Cr-0.39Al---0.99Mo-0.49V steel,

V1 system: 0.072C-0.21Si-1.19Mn-0.70Cu-1.20Ni-3.98Cr-0.40Al---0.15Mo-V steel,
V2 system: 0.074C-0.21Si-1.20Mn-0.73Cu-1.21Ni-4.03Cr-0.41Al---0.40Mo-V steel,
V3 system: 0.072C-0.20Si-1.19Mn-0.70Cu-1.20Ni-4.00Cr-0.40Al---0.65Mo-V steel, and
V4 system: 0.072C-0.22Si-1.20Mn-0.68Cu-1.22Ni-3.99Cr-0.41Al---0.90Mo-V steel

Steel L2 contains Mo and V in the lower limit amounts, and steel M2 contains Mo and V in the upper limit amounts. Further, steel V1 to V4 systems consist of 20 steel grades in which V is arbitrarily added within the range defined in item 9 above.
Looking at Fig. 7, even steel L2 has a hardness exceeding 35 HRC, which shows that according to the component systems of the steels of the invention, the hardness necessary for the die can be stably obtained. Paying attention to 0.5Mo+V>0.19 herein, an increase in hardness is observed, and it is apparent that this is a desirable region in the case of aiming to increase the hardness. When 0.5Mo+V>0.22, the hardness (appropriately 36 HRC or more) is further stably obtained.
[0078] Fig. 8 shows the relationship between the impact value and Mo+V. As the materials, there are used the same 22 steel grades as in Fig. 7. Compared to Figs. 5 to 7, the correlation is not simple. The reason for this is that influences of structural refinement, matrix embrittlement and crystallized materials are overlapped one another. In the case of increasing the amount of Mo, the impact value is increased up to a certain added amount because of structural refinement. On the other hand, an increase in solid solution amount embrittles the matrix, so that the impact value is decreased by excessive addition of Mo. When V is added, grains are refined up to a certain added amount thereof, resulting in an increase in the impact value. When V is excessively added, coarse crystallized materials mainly composed of V, C or N are generated at the time of coagulation in steel ingot production. These materials act as starting points, so that the impact value is decreased. Further, in the steel excessively containing V, VC is precipitated in γ grain boundaries at the time of cooling of quenching, which also contributes to a decrease in the impact value.
However, even though the impact value is decreased depending on the amounts of Mo and V, both levels exceed 25 J/cm^2. Among commercially available steel materials, there are many steels having an impact value of 15 J/cm^2 or less. This shows that the steels of the invention are stably high in toughness.
It can be seen that the impact value of the steels of the invention is stable within the range of 26 to 32 J/cm^2. However, paying attention to Mo+V<0.45 herein, this can be considered as a region in which the impact value is stabilized. When Mo+V<0.42, this tendency becomes more significant.
[0079] In this regard, with regard to each element contained in the steel of the present invention, according to an embodiment, the minimal amount thereof may be the amount in any one of the inventive steels as summarized in Table 3. According to a further embodiment, the maximum amount thereof may be the amount in any one of the inventive steels as summarized in Table 3. Furthermore, with regard to each formulae (Mn+Cr+0.5Ni and 0.5Mo+V) regarding the steel of the present invention, according to an embodiment, the minimal value thereof may be the value in any one

of the inventive steels as summarized in Table 3. According to a further embodiment, the maximum value thereof may be the value in any one of the inventive steels as summarized in Table 3.

[0080] By the way, an injection molding die for plastic products is provided with many water cooling holes for the purpose of a reduction in production time (molding in high cycles). The insides of the water cooling holes are under a corrosion environment due to water, and in addition, tensile stress acts thereon. A source of tensile stress is thermal stress at the time when a resin is injected or mechanical stress due to deflection of the die at the time of mold cramping or injection.

[0081] When tensile stress continues to act under the corrosion environment as described above, a crack occurs starting from a corroded part, and develop toward a design surface (molded surface). When the crack reaches the design surface, water leakage occurs, resulting in a failure to perform injection molding of the resin.
This phenomenon is called water cooling hole cracking. The die in which the water cooling hole cracking has occurred comes to be changed, which causes an increase in die cost or a decrease in productivity. That is to say, the water cooling hole cracking is a serious trouble, and should be avoided.

[0082] For the above reason, it becomes important to evaluate sensitivity of the water cooling hole cracking of the die. A test simulating the water cooling hole cracking will be described below.

[0083] Fig. 9 shows a method for testing whether a steel material is easily cracked or not, when the tensile stress acts under the corrosion environment. A test specimen is cylindrical and has a diameter of 6 mm, and a notch is formed near the center thereof. A notch part has a diameter of 4 mm.
Materials have the same alloy components as inventive steel 1, comparative steel 2 and comparative steel 3, which are described later.
The test specimen is supported in a cantilever form, and thereafter, a weight is hung from an end opposite to a fixed side, thereby adding bending force to the test specimen. At this time, the tensile stress always acts on an upper side of the notch part. Then, in this state, water is continuously dropped to the notch part. By the above, a situation is produced in which the tensile stress acts under the corrosion environment due to water. This simulates the water cooling cracking of the die.

[0084] In this test method, the time from hanging of the weight to breakage of the test specimen is evaluated. When the time to the breakage is longer, it can be judged to be a more excellent die material in which the water cooling cracking is difficult to occur.

[0085] In the test, the test specimens are set one by one on 5 testing devices, and evaluation of the same steel grade is performed on all the 5 testing devices in parallel. Then, the time when one of the 5 specimens is broken is recorded as the "breaking time", and the test is finished (even when the remaining 4 specimens are not broken).

[0086] Fig. 10 shows the breaking time in the case where a load of 44 [N] was put on each of 3 steel grades refined to 39 HRC. Inventive steel 1 had a breaking time of about 1.5 times that of comparative steel 2 and about 300 times that of comparative steel 3. That is to say, when the tensile stress acts thereon under the corrosion environment, inventive steel 1 is difficult to be broken, and therefore can be judged as an excellent die material in which the water cooling cracking is difficult to occur.

[0087] As described above, steel of the invention is characterized by that the water cooling cracking is difficult to occur. This is because the corrosion resistance is high, which makes it difficult to generate a corroded part, and the toughness is high, which makes it difficult to rapidly develop a crack. Further, the steel material is embrittled by hydrogen entering from water to promote breakage. The main reason for the difficulty of the steel of the invention to be broken is also that the kind and amount of precipitates (the intermetallic compound composed of Ni and Al, aging precipitated Cu and MnS, and the like) which trap hydrogen to render it harmless are proper.

[0088] Further, the steel of the invention is characterized by that the heat treatment hardness is easily adjustable and difficult to depart from a severe hardness standard. Description will be made herein taking as an example the case where a hardness standard within the narrow range of 39 to 41 HRC is required.
Materials have the same alloy components as inventive steel 1 and comparative steel 1, which are described later.

[0089] Fig. 11 shows changes in hardness to the tempering temperature of inventive steel 1 and comparative steel 1. In comparative steel 1, in order to satisfy the standard of 39 to 41 HRC, it is necessary to soak the steel material within the range of 10°C from 550 to 560°C. Accordingly, tempering conditions to be set are 555°C $\times$ 5 hr.

[0090] The temperature fluctuation range during soaking in a heat treating furnace is generally from 5 to 15°C. Further, even when the temperature fluctuation range during soaking is extremely small, a difference in temperature of 5 to 15°C is generated between positions in the furnace. Addition of both the differences in temperature results in generation of a difference in temperature of up to about 30°C.

[0091] Accordingly, comparative steel 1 is actually heated at 540 to 570°C even when soaking at 555°C is intended. Looking at Fig. 11, this heating condition corresponds to a condition for giving 37 to 42 HRC. That is to say, it is extremely difficult to refine steel 1 for comparison to the narrow range of 39 to 41 HRC, and the hardness in cross-section becomes 37 to 42 HRC.
When the hardness varies according to sites in the steel material, the machinability and the mirror polishing properties

are unfavorably deteriorated.

[0092] On the other hand, inventive steel 1 may be heated in a temperature region of 527°C or less, in order to satisfy the standard of 39 to 41 HRC. Tempering conditions to be set are, for example, 510°C × 5 hr. From the problem of the variation in furnace temperature described above, the steel of the invention is actually heated at 495 to 525°C. Nevertheless, a hardness of approximately 40 HRC is obtained.

[0093] As described above, the steel of the invention is characterized by that the hardness is easily controllable within the narrow range. This is an effect of making proper the amounts of the carbide containing Cr, Mo or V, the intermetallic compound composed of Ni and Al, and Cu precipitated by adjusting the balance of C-Cr-Mo-V-Cu-Ni-Al, thereby reducing changes in hardness to the tempering temperature.

EXAMPLES

[0094] Thirty-nine kinds of steels having compositions shown in Table 3 (blank columns in Table 3 indicate that the chemical components are at the impurity level) were melted in the atmosphere, and each casted into an ingot of 7 tons. After homogenized heat treatment at 1,200 to 1,300°C, the ingot of each steel material was forged into a block form of 210x 1,020x3,500 (mm) within the surface temperature range of 900 to 1,250°C.

Table 3

		C	Si	Mn	Cu	Ni	Cr	Al	Mo	V	W, Co	Nb, Ta, Ti, Zr	B	S, Ca, Se, Te, Bi, Pb	Hardenability Mn+Cr+0.5Ni	Secondary precipitation of carbide 0.5Mo+V
Inventive steel	1	0.079	0.21	1.19	0.70	1.19	3.98	0.38	0.40	0.10					5.77	0.30
	2	0.078	0.18	1.22	0.68	1.23	4.01	0.40	0.39	0.11				S:0.015	5.85	0.31
	3	0.061	0.20	1.21	0.71	1.21	3.97	0.40	0.39	0.10				S:0.026	5.79	0.30
	4	0.094	0.20	1.18	0.71	1.14	3.99	0.40	0.38	0.09				Ca:0.007	5.74	0.28
	5	0.081	0.06	1.20	0.70	1.20	4.00	0.42	0.11	0.17		Ti : 0.009	0.0005		5.80	0.23
	6	0.080	0.11	1.19	0.69	1.21	3.97	0.40	0.46				0.0010		5.77	0.23
	7	0.080	0.27	1.20	0.70	1.22	4.00	0.41		0.23		Ti : 0.027	0.0026		5.81	0.23
	8	0.081	0.19	1.12	0.69	1.19	4.02	0.39	0.44	0.12					5.74	0.34
	9	0.086	0.20	1.37	0.69	1.22	3.93	0.39	0.38	0.09					5.91	0.28
	10	0.080	0.22	1.20	0.41	1.20	4.00	0.40	0.38	0.10	W:0.48				5.80	0.29
	11	0.082	0.20	1.18	0.57	1.20	4.00	0.39	0.36	0.16	Co:0.51				5.78	0.34
	12	0.080	0.18	1.19	0.74	1.18	3.98	0.40	0.40	0.16	W:1.06 Co:0.98				5.76	0.36
	13	0.093	0.20	1.20	0.74	0.40	4.03	0.15	0.42	0.19					5.43	0.40
	14	0.083	0.20	1.20	0.69	0.93	3.96	0.31	0.46	0.14					5.63	0.37
	15	0.069	0.19	1.20	0.53	1.38	3.50	0.45	0.44	0.12					5.39	0.34
	16	0.065	0.21	1.28	0.32	1.54	3.24	0.46	0.36	0.07					5.29	0.25
	17	0.097	0.21	1.12	0.70	1.70	3.24	0.34	0.40	0.08		Nb:0.008			5.21	0.28
	18	0.086	0.20	1.12	0.72	0.68	4.58	0.23	0.24	0.16		Nb:0.022			6.04	0.28
	19	0.073	0.19	1.12	0.60	0.33	5.50	0.11	0.36	0.13		Nb:0.059			6.79	0.31
	20	0.064	0.15	1.12	0.68	0.36	6.47	0.12	0.36	0.12		Ti:0.016			7.77	0.30
Inventive steel	21	0.053	0.08	1.12	0.60	0.33	7.53	0.12	0.64	0.06		Ti:0.032			8.82	0.38
	22	0.041	0.04	1.12	0.72	0.33	8.59	0.11	0.40	0.18		Nb: 0.040 Ti:0.023			9.88	0.38

(continued)

		C	Si	Mn	Cu	Ni	Cr	Al	Mo	V	W, Co	Nb, Ta, Ti, Zr	B	S, Ca, Se, Te, Bi, Pb	Hardenability Mn+Cr+0.5Ni	Secondary precipitation of carbide 0.5Mo+V
	23	0.098	0.19	1.20	0.76	1.05	3.80	0.35	0.12	0.35				S:0.006	5.53	0.41
	24	0.088	0.20	1.19	0.61	0.80	3.84	0.27	0.26	0.22				S:0.035	5.43	0.35
	25	0.077	0.20	1.12	0.47	0.54	3.82	0.18	0.55	0.08				S:0.047	5.21	0.36
	26	0.067	0.23	1.12	0.31	0.34	3.95	0.11	0.69	0.06					5.24	0.41
	27	0.042	0.17	1.18	0.48	0.74	4.01	0.25	0.89	0.49					5.56	0.94
	28	0.055	0.20	1.20	0.50	0.84	4.02	0.28	0.82						5.64	0.41
	29	0.056	0.20	1.41	0.52	1.28	3.99	0.49		0.39					6.04	0.39
	30	0.071	0.22	1.14	0.49	0.63	3.36	0.21	0.41	0.09					4.82	0.30
	31	0.073	0.21	1.13	0.50	0.94	3.38	0.32	0.38	0.08					4.98	0.27
	32	0.072	0.22	1.15	0.62	1.08	3.84	0.36	0.10	0.05					5.53	0.10
	33	0.073	0.22	1.14	0.42	0.49	3.84	0.16	0.18	0.08					5.23	0.17
Comparative steel	1	0.110	0.45	1.48	0.91	3.12	0.26	1.01	0.27						3.30	0.14
	2	0.070	1.19	0.45	0.45	3.05	4.05	0.74	0.98						6.03	0.49
	3	0.110	0.25	2.54		1.00	3.00		0.28	0.04					6.04	0.18
	4	0.180	0.30	1.60			2.30		0.40	0.10				S:0.010	3.90	0.30
	5	0.270	0.23	0.44			7.90		0.49	0.64					8.34	0.89
	6	0.360	0.97	0.26			13.60			0.22					13.86	0.22

[0095] This block was reheated at 900°C. After keeping for 3 hours, the block was immersed in oil of 40 to 100°C to perform quenching. Further, the block was kept in a temperature region of 350 to 560°C for 5 hours to adjust the hardness to 35 to 43 HRC by refining. Using a material cut out from near the center of the block after refining, there were evaluated the machinability, the impact value, the thermal conductivity, the mirror surface properties, the weldability, the corrosion resistance, the sensitivity of water cooling hole cracking and variations in hardness. Further, production cost was also evaluated.

[0096] The thermal conductivity is a value measured by a laser flash method at 200°C. The larger number is preferred because the die formed is more excellent in cooling performance.

[0097] The mirror polishing properties mean the upper limit grain size which generates no defect (such as undulation, tarnish and pin holes) on a surface of the steel material, when polished with an abrasive with changing the grain size thereof. The larger this number, the smaller the abrasive grain of the abrasive, which means that the steel material can be finely polished. Such a steel material is preferred because of being usable for the higher-grade die.

[0098] Although not so much as the thermal conductivity and the mirror polishing properties, the other characteristics are important because of being related to productivity, maintenance properties and cost of the die. These are represented by symbols of relative comparison. Evaluation comes down in order of ◎ → ○ → Δ → ×.

[0099] The machinability was judged by a wear state of a cutting tool at the time when a cutting distance of 1,000 mm was cut, standardizing the cut amount and the feed rate. The case where the wear amount of the cutting tool was small (≤150 μm) and the wear was normal was indicated as ◎, the case where the wear amount was large (<300 μm) was indicated as ○, the case where the wear amount was further increased (≥300 μm) and the abnormal wear was observed was indicated as Δ, and the case where in addition to the abnormal wear, the tool was chipped was indicated as ×.

[0100] The impact value was judged by the value of a 2 mm U-notch test specimen (JIS No. 3) at room temperature. That is to say, the case where the impact value was 40 J/cm^2 or more was indicated as ◎, the case where the impact value was from 30 to less than 40 J/cm^2 was indicated as ○, the case where the impact value was from 20 to less than 30 J/cm^2 was indicated as Δ, and the case where the impact value was less than 20 J/cm^2 was indicated as ×.

[0101] The weldability was judged from the results obtained by performing multi-pass welding using a proper welding rod appropriate for the C amount, cutting a welded part, and examining hardness distribution and cracks. That is to say, the case where there were no cracks and no site in which the hardness was significantly decreased was indicated as ◎, the case where there were no cracks but a site in which the hardness was decreased was indicated as ○, the case where there were no cracks but a site in which the hardness was largely decreased was indicated as Δ, and the case where cracks occurred was indicated as ×.

[0102] The corrosion resistance (weather resistance) was judged from the degree of rust at the time when the mirror-polished material was allowed to stand on the shore in an environment exposed to rain for 1 month. That is to say, the case where the material was hardly rusted or point-like corroded parts were slightly observed was indicated as ◎, the case where point-like corroded parts were remarkable was indicated as ○, the case where corroded parts were connected together to form rust widely spread was indicated as Δ, and the case where a rust region was further spread to decrease a metallic luster part was indicated as ×.

[0103] The sensitivity of water cooling hole cracking was evaluated by the test method described above. The test was performed putting a load of 90% of the bending breaking strength on all the materials. The breaking time in this case was evaluated as the sensitivity of water cooling hole cracking.

[0104] The variation in hardness is a difference between the maximum value and the minimum value of the HRC hardness measured at 5 places (near 4 corners and the center) on a surface of a block material.
The respective sites of the block material do not have the same hardness under the influence of the variation in furnace temperature. As an index of "ease of controlling the hardness" described above, the variation in hardness was evaluated. The smaller variation in hardness means that the hardness falls in a narrower range even when the furnace temperature fluctuates, so that such a material is a steel material which is easily controllable in hardness.

[0105] The results thereof are shown in Table 4.
First, description will be made with respect to the inventive steels. Of particular note is the high hardness of the thermal conductivity, which is stably 26 W/(m·K) or more. In particular, the steels other than inventive steels 19 to 22 secure a hardness of 28 W/(m·K) or more. That is to say, deficiency in cooling performance of the die is difficult to occur. Further, also for the mirror polishing properties, grain size #8,000 or more is satisfied, so that the steels of the invention can be used for the die having a high surface quality level. The steels of the invention has no "×" for the other characteristics, which are qualitatively evaluated by symbols, and it is obvious at a glance that they are good in balance of the various characteristics. Although only some steels have "Δ" in machinability and cost, there is no problem in any way, from the viewpoint of balance with the other characteristics. That is to say, the steels of the invention have high thermal conductivity and mirror polishing properties as basic performances, and are also excellent in the other characteristics and cost performance. Further, the average hardness at room temperature is also within the range of 35 to 45 HRC.

[0106] Furthermore, in all the steels of the invention, the breaking time in the test which simulates the water cooling hole cracking exceeds 100 hours. There are no steels of the invention which are broken within several hours or tens of

hours, so that it is considered that the water cooling hole cracking is difficult to occur.
In addition, the variation in hardness falls within 3. In particular, in all the steels except for inventive steels 18 to 22, the variation in hardness is within 2. That is to say, even when a narrow hardness standard is required, the steels of the invention can comply therewith.

[0107] The comparative steels will be described below. Comparative steel 1 is excellent in mirror polishing properties, and also high in thermal conductivity and machinability. On the other hand, it has defects in impact value and corrosion resistance, which causes problems of cracking and rust. Comparative steel 2 is excellent in mirror polishing properties and also good in weldability. On the other hand, it has defects in thermal conductivity and impact value, which causes problems of deficiency in cooling performance of the die and cracking. Comparative steel 3 is a steel material fairly well balanced. However, the cooling performance of the die is deficient because of its low thermal conductivity. In nowadays in which molding in high cycles has been demanded, this is a fetal defect. Further, the cost is not cheap, and expensive for the steel material characteristics. Comparative steel 4 is high in thermal conductivity and also good in machinability. On the other hand, it has defects in corrosion resistance and mirror polishing properties, so that the range of application thereof is considerably limited. Comparative steel 5 is excellent in mirror polishing properties and also good in corrosion resistance. On the other hand, it has defects in machinability and thermal conductivity, which causes problems of difficulty of die machining and deficiency in cooling performance of the die. Comparative steel 6 is excellent in mirror polishing properties and also good in corrosion resistance. On the other hand, it has defects in machinability, impact value, weldability and thermal conductivity, which causes problems of difficulty of die machining or repairs and further deficiency in cooling performance of the die.

[0108] Further, in some steels for comparison, the breaking time in the test which simulates the water cooling hole cracking is as extremely low as less than 40 hours. Such steels are considered to be at high risk of occurrence of the water cooling hole cracking.
Furthermore, in some steels, the variation in hardness exceeds 3, and when a narrow hardness standard is required, such steels are difficult to comply therewith.

Table 4

		HRC	Machinability	Impact value	Thermal conductivity	Mirror surface properties	Weldability	Corrosion resistance	Sensitivity of water cooling hole cracking	Variation in hardness	Cost
Inventive Steel	1	40.1	O	O	29.6	14000	O	Δ	123	1.6	O
	2	39.7	◎	O	29.3	8000	O	Δ	118	1.5	O
	3	40.0	◎	O	29.4	8000	◎	Δ	109	1.7	O
	4	39.6	◎	O	29.1	8000	O	Δ	114	1.8	O
	5	35.7	Δ	O	31.1	14000	O	Δ	122	1.7	O
	6	39.8	O	O	29.5	14000	O	Δ	113	1.7	O
	7	40.0	O	O	29.5	14000	O	Δ	121	1.8	O
	8	40.3	O	O	29.2	14000	O	Δ	117	1.8	O
	9	39.6	O	O	29	14000	O	Δ	119	1.7	O
	10	39.1	O	O	29.2	14000	O	Δ	112	1.6	O
	11	40.2	O	O	29.6	14000	O	Δ	107	1.7	O
	12	42.1	O	O	28.8	14000	O	Δ	118	1.7	O
	13	40.3	O	O	29	14000	O	Δ	115	1.6	O
	14	38.1	O	O	29	14000	O	Δ	109	1.5	O
	15	40.1	O	O	28.9	14000	◎	Δ	115	1.6	O
	16	39.8	O	O	29.3	14000	◎	Δ	110	1.8	O
	17	40.0	O	O	29.4	14000	O	Δ	113	1.9	O
	18	39.1	O	◎	28.1	14000	O	O	126	2.1	O
	19	40.0	O	◎	27.6	14000	◎	O	128	2.2	O
	20	39.3	O	◎	26.4	14000	◎	◎	131	2.4	O

(continued)

		HRC	Machinability	Impact value	Thermal conductivity	Mirror surface properties	Weldability	Corrosion resistance	Sensitivity of water cooling hole cracking	Variation in hardness	Cost
Inventive Steel	21	38.2	O	◎	26.2	14000	◎	◎	146	2.5	O
	22	37.0	Δ	◎	26.1	14000	◎	◎	171	2.6	O
	23	40.6	◎	O	29.3	8000	O	Δ	117	1.8	O
	24	40.4	◎	O	28.9	8000	O	Δ	110	1.7	O
	25	40.1	◎	O	29.4	8000	◎	Δ	119	1.8	O
	26	39.8	O	O	29	14000	◎	Δ	108	1.8	O
	27	41.3	O	Δ	29.2	14000	◎	Δ	109	1.4	Δ
	28	40.0	O	O	29	14000	◎	Δ	120	1.7	O
	29	40.2	O	O	29.4	14000	◎	Δ	111	1.6	O
	30	39.5	O	Δ	29.4	14000	◎	Δ	120	1.6	O
	31	39.2	O	Δ	29.4	14000	◎	Δ	109	1.7	O
	32	35.9	O	○	29.2	14000	◎	Δ	113	1.5	O
	33	36.1	O	○	29.3	14000	◎	Δ	122	1.6	O
Comparative Steel	1	39.8	◎	×	32.3	14000	O	×	170	3.8	×
	2	40.3	Δ	×	25.5	14000	◎	Δ	143	1.7	×
	3	38.9	Δ	O	25.1	8000	O	Δ	3	1.8	Δ
	4	32.4	O	O	36.8	3000	Δ	×	39	2.9	◎
	5	46.7	×	Δ	24.2	14000	Δ	O	169	3.6	×
	6	49.8	×	×	22.8	14000	×	◎	448	2.7	Δ

[0109] As described above, comparative steels have problems in characteristics and cost. Inventive steels have high thermal conductivity and mirror polishing properties while securing a hardness of 35 HRC or more, and are also excellent in the other characteristics and cost performance.
These are effects achieved by making the Si amount proper and a proper combination of 3 types of dispersion strengthening mechanisms.
The 3 types of dispersion strengthening mechanisms are (1) the secondary precipitation of the carbide mainly composed of Mo or V, (2) the aging precipitation of Cu and (3) the aging precipitation of the intermetallic compound composed ofNi and Al. Moreover, the invention is also characterized by achievement of (2) and (3) in a state where the alloy element amount is smaller than that of the conventional steels, thereby balancing the strength with the other characteristics.
[0110] While the invention has been described in detail and with reference to specific embodiments thereof, it will be apparent to one skilled in the art that various changes and modifications can be made therein without departing from the scope thereof.

Claims

1. A steel for a molding die, the steel containing, by mass%,

$$0.040 < C < 0.100,$$

$$0.03 < Si < 0.28,$$

$$1.11 < Mn < 1.45,$$

$$0.30 < Cu < 0.77,$$

$$0.30 < Ni < 1.78,$$

$$3.23 < Cr < 9.00,$$

$$0.10 < Al < 0.50;$$

and
at least one of:

$$0.04 < Mo < 1.00$$

and

$$0.02 < V < 0.50,$$

and optionally comprising:

$$W \leq 4.00,$$

$$Co \leq 3.00,$$

$$Nb \leq 0.100,$$

$$Ta \leq 0.100,$$

$$Ti \leq 0.100,$$

$$Zr \leq 0.100,$$

$$B \leq 0.0050,$$

$$S \leq 0.050,$$

$$Ca \leq 0.2000,$$

$$Se \leq 0.50,$$

$$Te \leq 0.100,$$

$$Bi \leq 0.30$$

and

$$Pb \leq 0.50,$$

with the balance Fe and inevitable impurities.

2. The steel for a molding die according to claim 1, further comprising, by mass%, at least one of:

$$0.30 < W \leq 4.00$$

and

$$0.30 < Co \leq 3.00.$$

3. The steel for a molding die according to claim 1 or 2, further comprising, by mass%, at least one of:

$$0.004 < Nb \leq 0.100,$$

$$0.004 < Ta \leq 0.100,$$

$$0.004 < Ti \leq 0.100$$

and

$$0.004 < Zr \leq 0.100.$$

4. The steel for a molding die according to any one of claims 1 to 3, further comprising, by mass%, $0.0001 < B \leq 0.0050$.

5. The steel for a molding die according to any one of claims 1 to 4, further comprising, by mass%, at least one of:

$$0.003 < S \leq 0.050,$$

$$0.0005 < Ca \leq 0.2000,$$

$$0.03 < Se \leq 0.50,$$

$$0.005 < Te \leq 0.100,$$

$$0.01 < Bi \leq 0.30$$

and

$$0.03 < Pb \leq 0.50.$$

6. The steel for a molding die according to any one of claims 1 to 5, which has an average hardness at room temperature within the range of 35 to 45 HRC.

7. The steel for a molding die according to any one of claims 1 to 6, which has a thermal conductivity measured by a laser flash method at 200°C of 26 W/(m.K) or more.

8. The steel for a molding die according to any one of claims 1 to 7, which satisfies, by mass%,

$$5.00 < Mn + Cr + 0.5\ Ni < 6.20.$$

9. The steel for a molding die according to any one of claims 1 to 8, which satisfies, by mass%,

$$0.19 < 0.5\ Mo + V < 0.45.$$

10. Use of the steel of one of claims 1 to 9, for the manufacture of a molding die.

FIG. 1

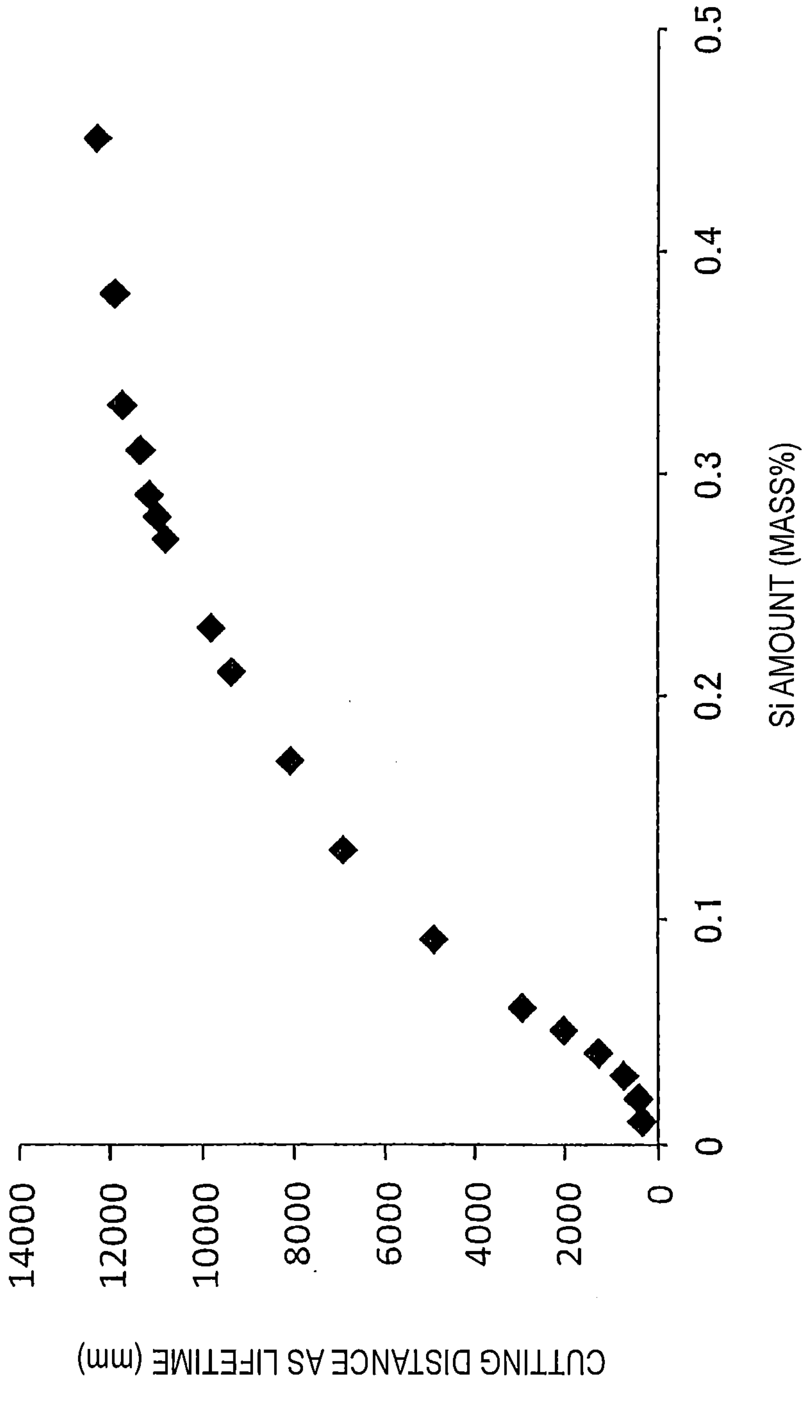

CUTTING DISTANCE AS LIFETIME (mm)
14000
12000
10000
8000
6000
4000
2000
0
Si AMOUNT (MASS%)
0
0.1
0.2
0.3
0.4
0.5

FIG. 2

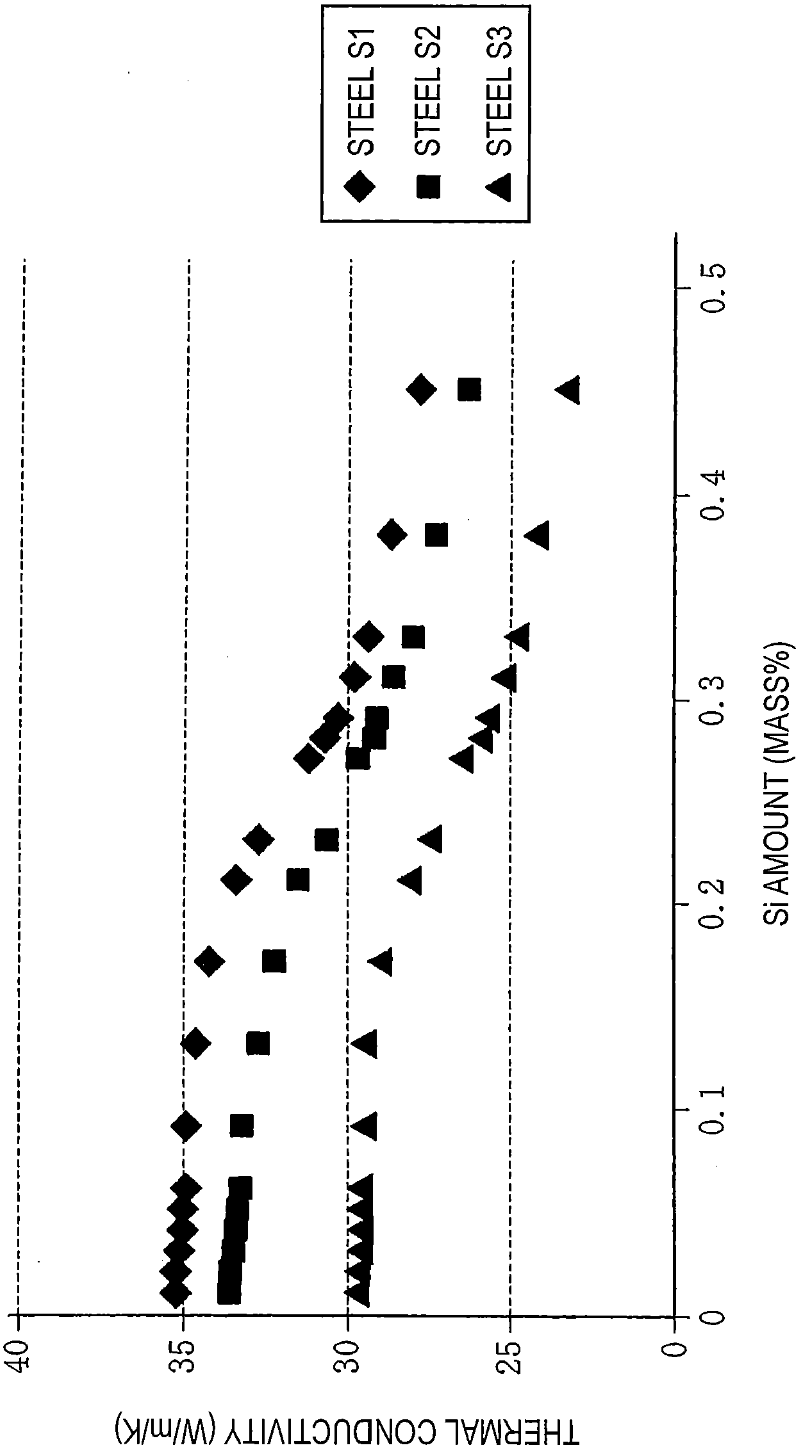

STEEL S1
STEEL S2
STEEL S3
THERMAL CONDUCTIVITY (W/m/K)
40
35
30
25
0
0
0.1
0.2
0.3
0.4
0.5
Si AMOUNT (MASS%)

FIG. 3

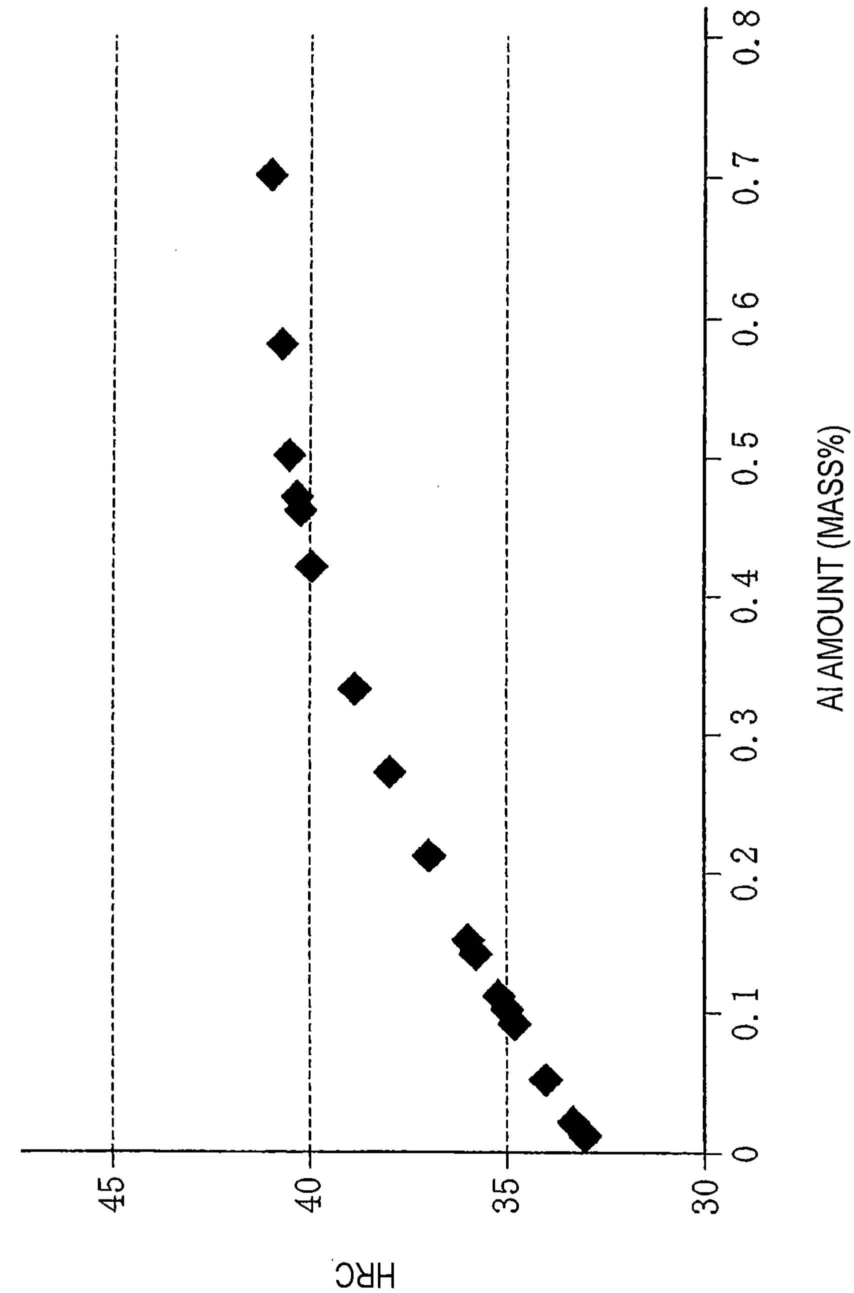


FIG. 4

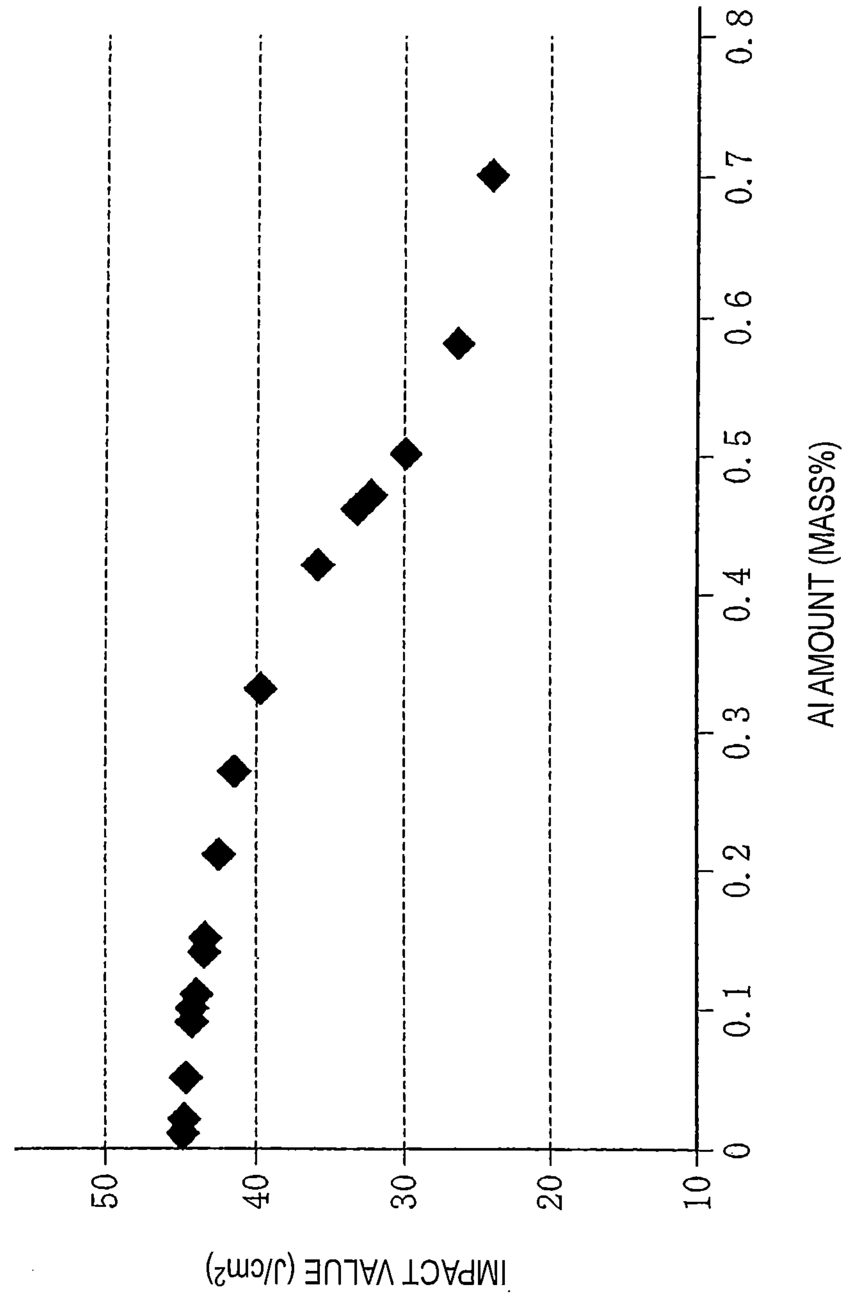

IMPACT VALUE (J/cm²)
50
40
30
20
10
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
Al AMOUNT (MASS%)

FIG. 5

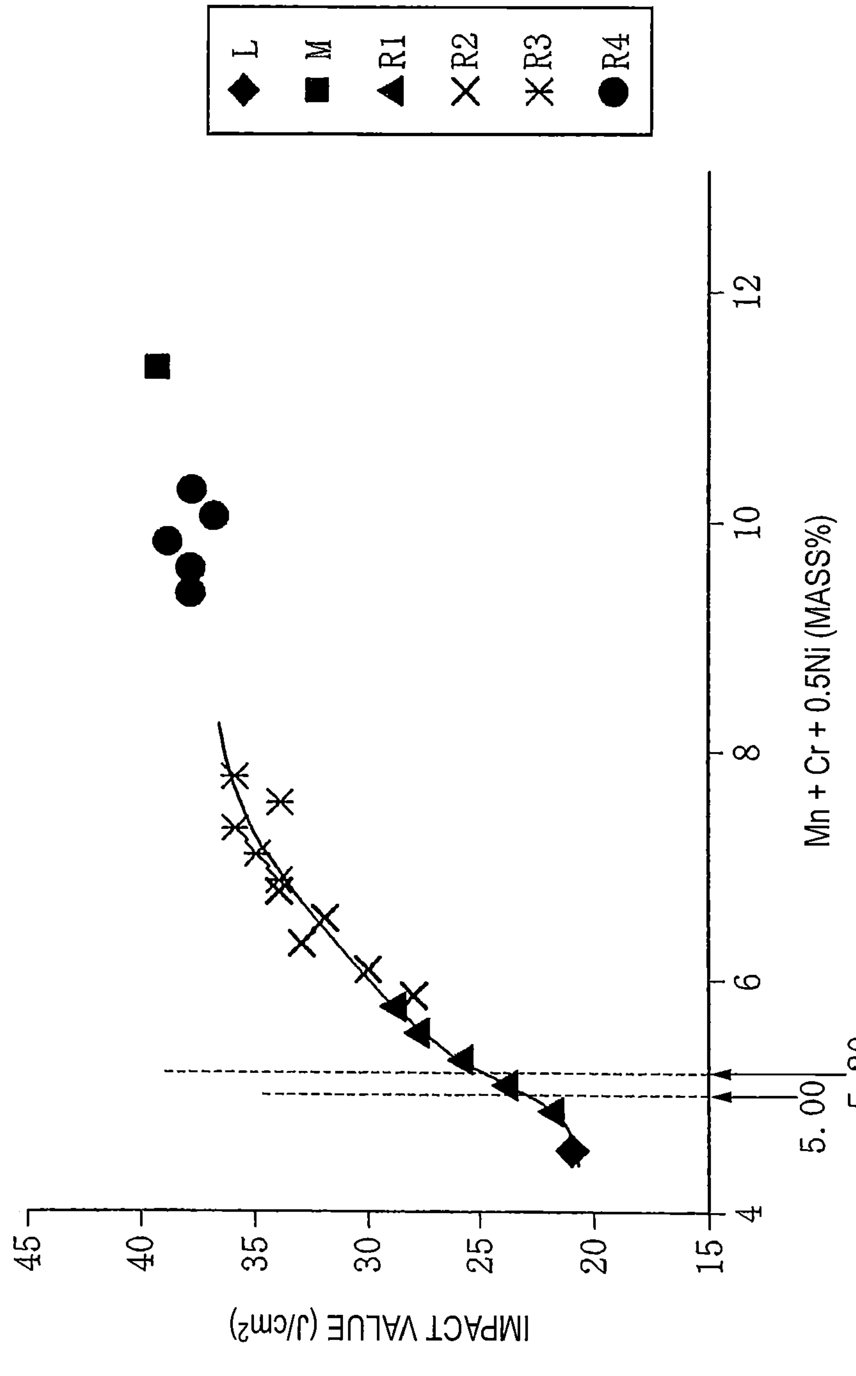

L
M
R1
R2
R3
R4
IMPACT VALUE (J/cm²)
45
40
35
30
25
20
15
4
5. 00
5. 20
6
8
10
12
Mn + Cr + 0.5Ni (MASS%)

FIG. 6

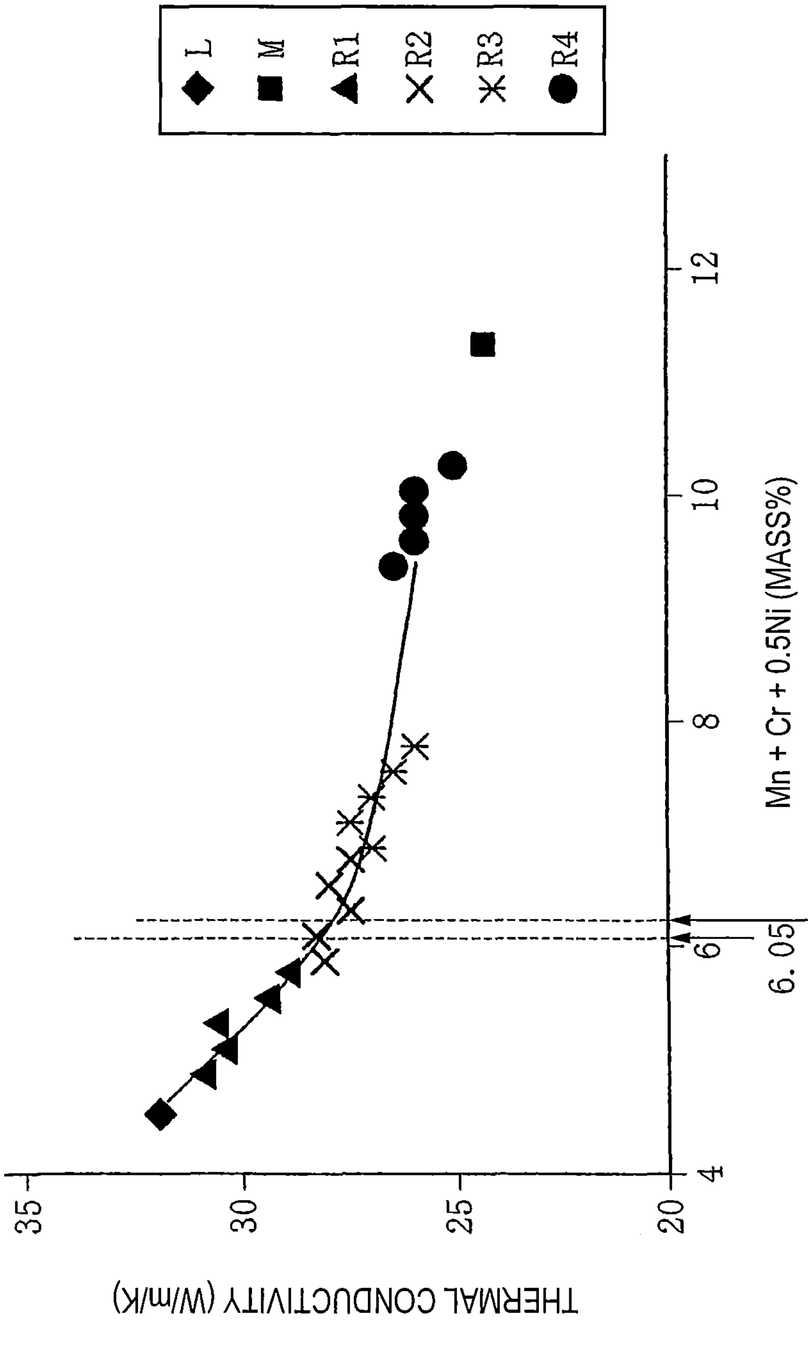

L
M
R1
R2
R3
R4
THERMAL CONDUCTIVITY (W/m/K)
35
30
25
20
4
6
8
10
12
6. 05
6. 20
Mn + Cr + 0.5Ni (MASS%)

FIG. 7

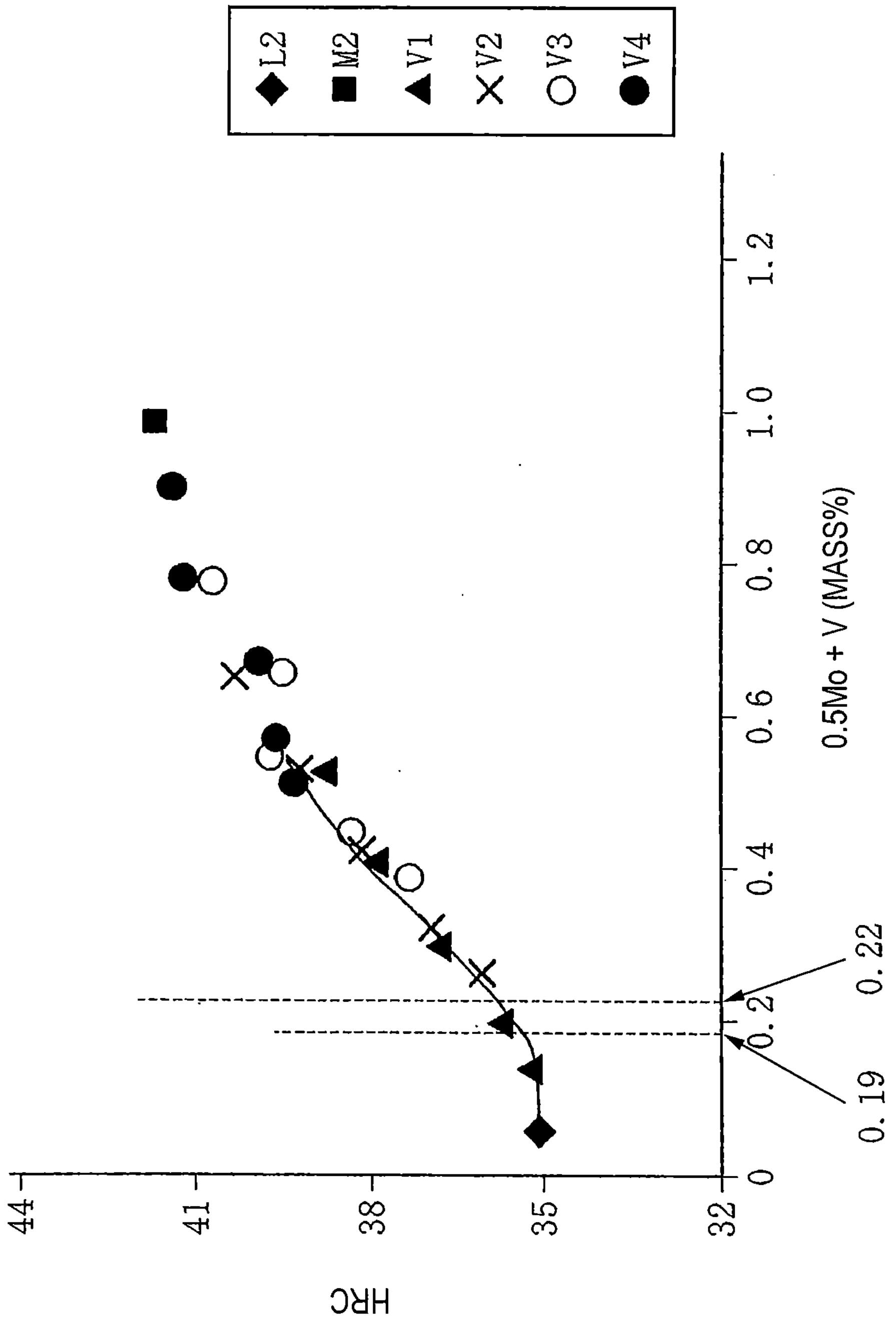

L2
M2
V1
V2
V3
V4
HRC
44
41
38
35
32
0
0.2
0.4
0.6
0.8
1.0
1.2
0.5Mo + V (MASS%)
0.19
0.22

FIG. 8

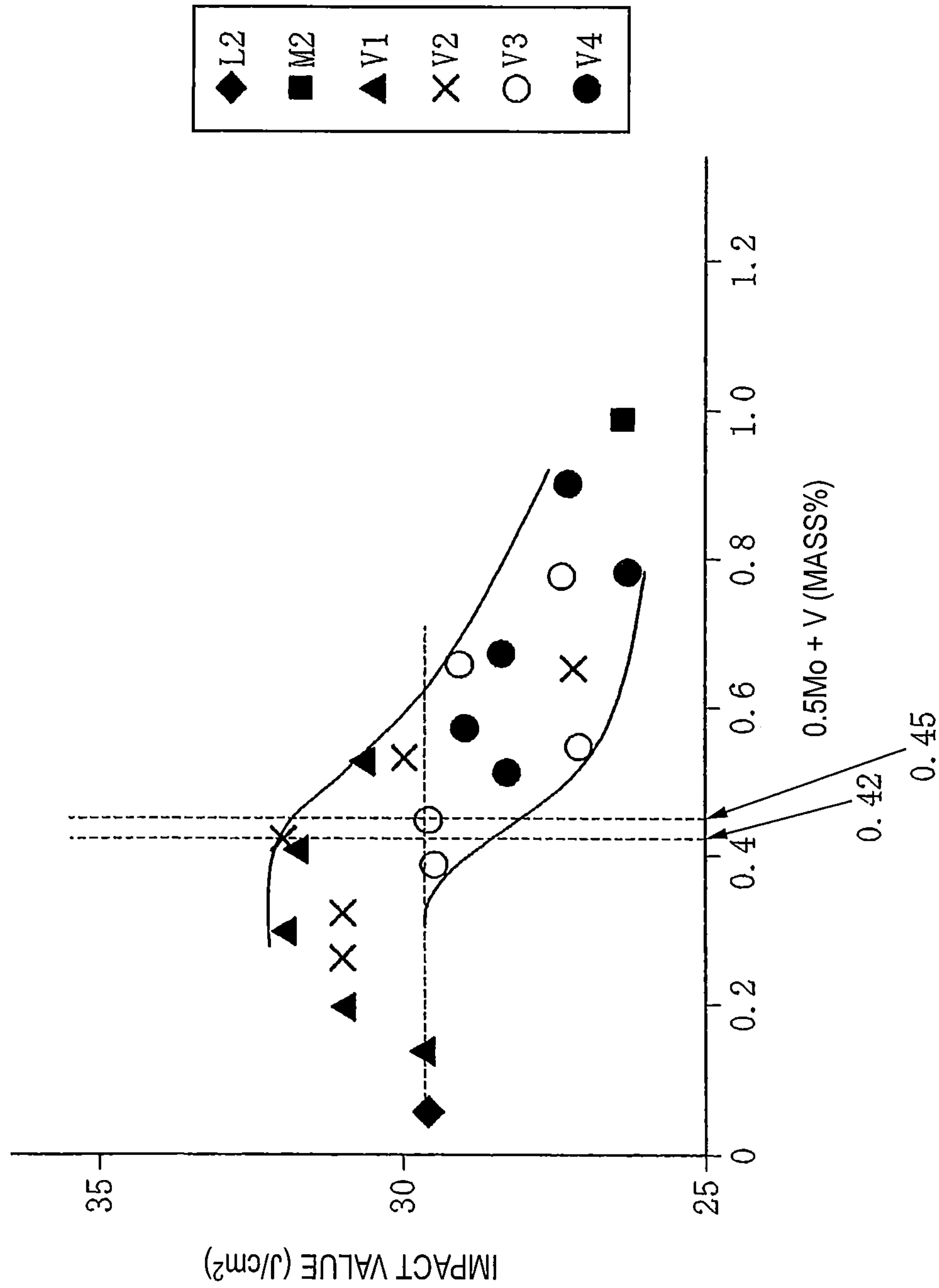

L2
M2
V1
V2
V3
V4
IMPACT VALUE (J/cm²)
35
30
25
0
0.2
0.4
0.6
0.8
1.0
1.2
0.5Mo + V (MASS%)
0.42
0.45

FIG. 9

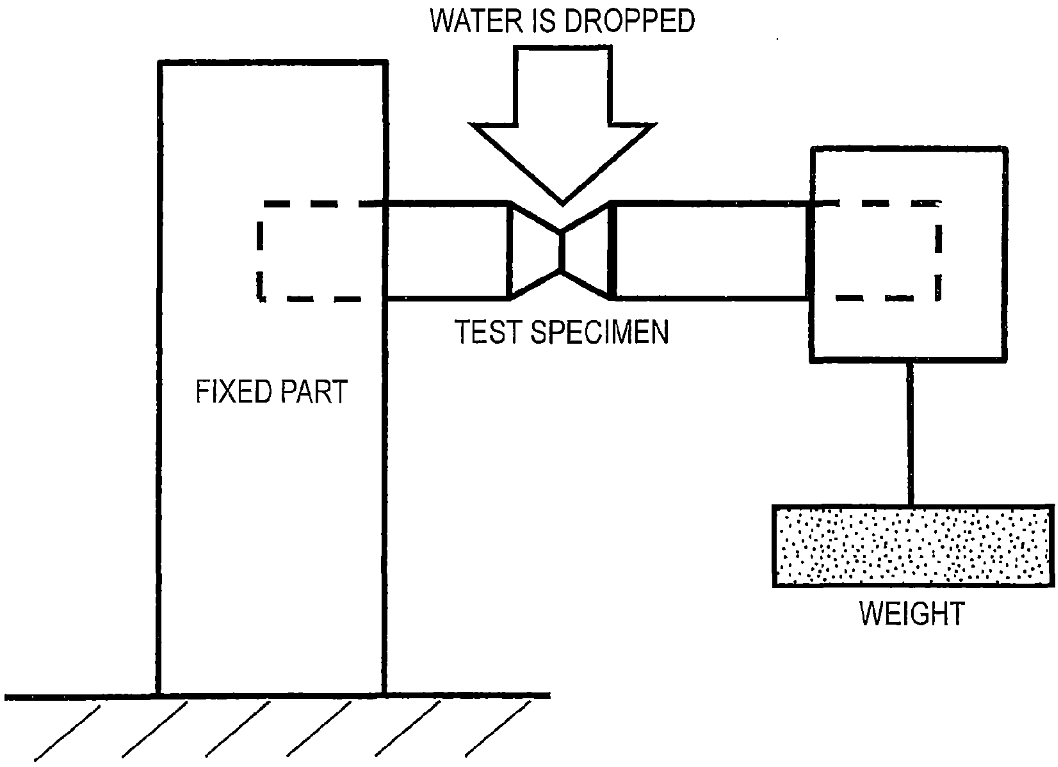
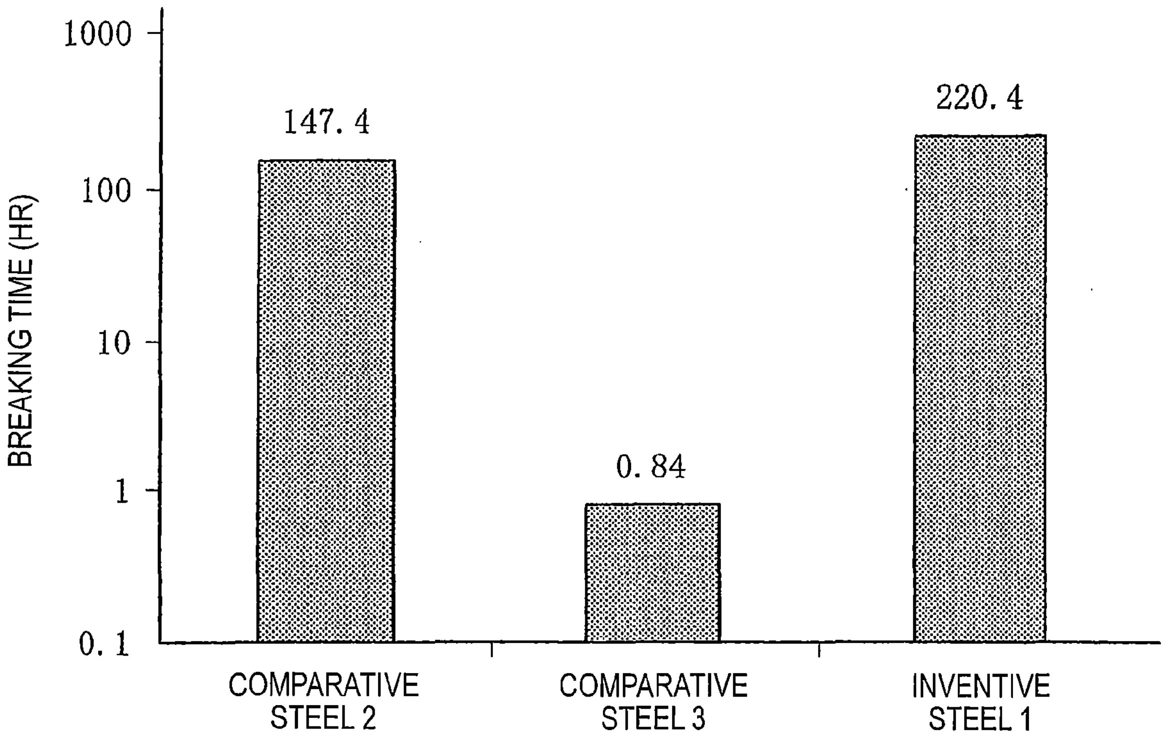
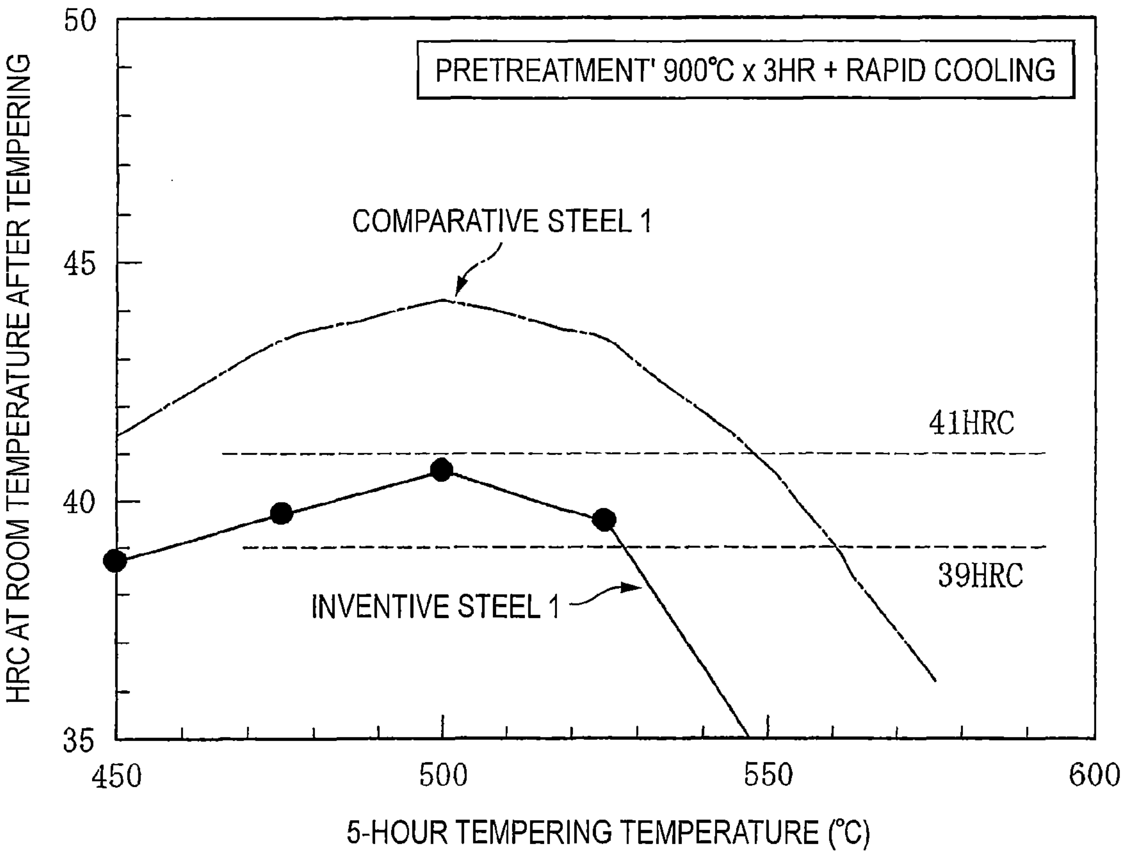


FIG. 10



RESULTS OF TEST SIMULATING WATER COOLING HOLE CRACKING

FIG. 11



CHANGES IN HARDNESS TO TEMPERING TEMPERATURE

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EUROPEAN SEARCH REPORT

Application Number
EP 13 16 6415

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
A	WO 2012/090562 A1 (HITACHI METALS LTD [JP]; FUKUMARU TAISHIROH [JP]; FUKUMARU MARIKO [JP]) 5 July 2012 (2012-07-05) * claims 1-6; tables 1-7 *	1-10	INV. C21D1/25 C22C38/06 C22C38/42 C22C38/44 C22C38/46 C22C38/54
A	US 2003/066577 A1 (ISHIDA KIYOHITO [JP] ET AL) 10 April 2003 (2003-04-10) * claims 1-27; tables 1-28 *	1-10	
A	JP 2000 054068 A (HITACHI METALS LTD) 22 February 2000 (2000-02-22) * abstract; tables 1-4 *	1-10	
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TECHNICAL FIELDS SEARCHED (IPC)

C21D
C22C

The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
Munich	10 January 2014	Catana, Cosmin

CATEGORY OF CITED DOCUMENTS

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- JP 2000297353 A **[0015]**