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(54) COLD WORKING DIE STEEL

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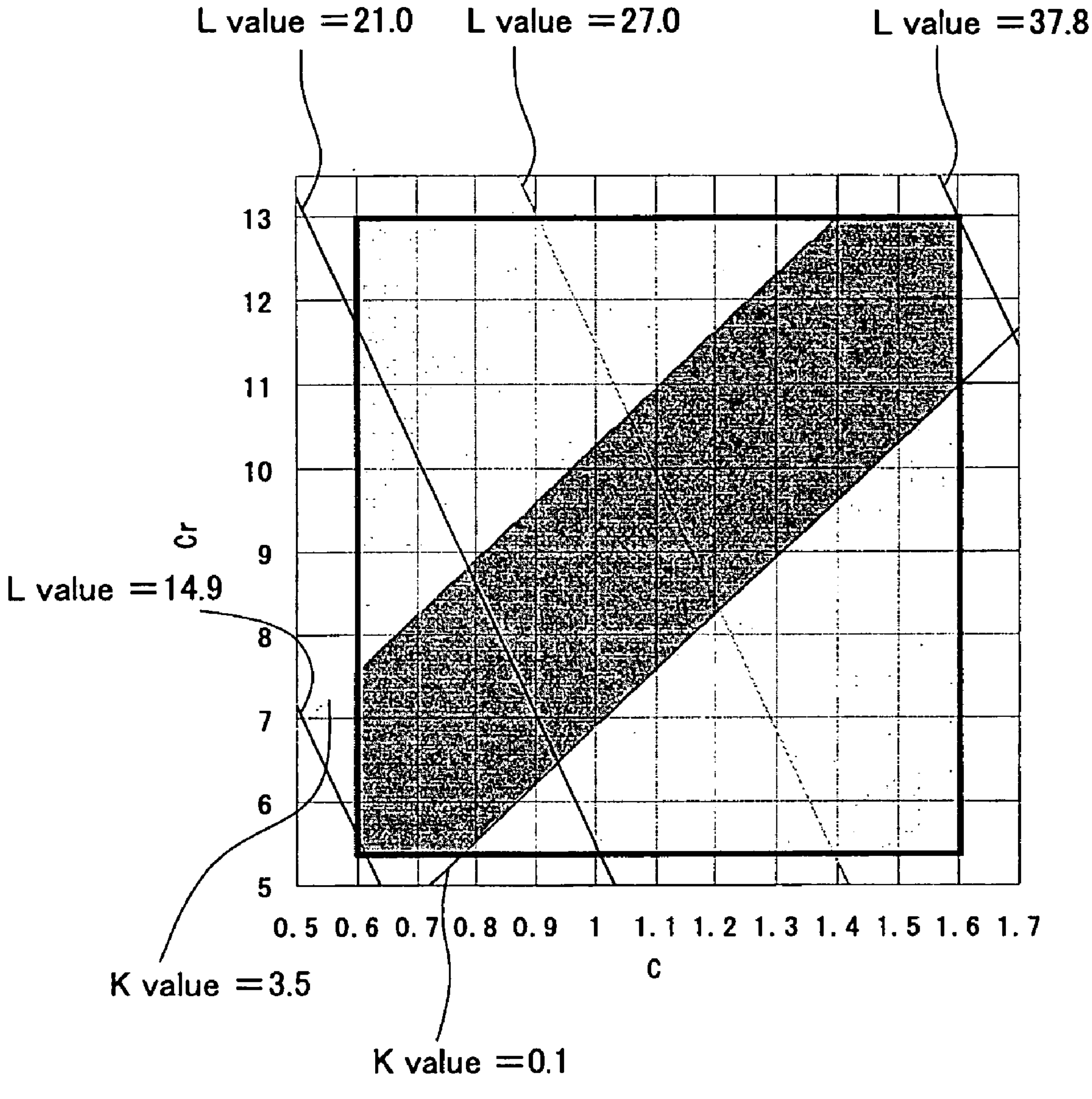
(57) **ABSTRACT**

This invention is aimed at providing a cold working die steel successfully reduced in the hardness, and increased in readiness in the cold workability (forging, pressing and so forth) and machinability (milling, drilling, endmilling processing, grinding and lathe turning). A cold working die steel aimed at solving the above-described subject consists essentially of, in % by mass, $0.6\% \leqq C \leqq 1.60\%$, $0.10\% \leqq Si \leqq 1.20\%$, $0.10\% \leqq Mn \leqq 0.60\%$, $5.5\% \leqq Cr \leqq 13.0\%$, $0.80\% \leqq Mo+0.5W \leqq 2.10\%$, $0.10\% \leqq V \leqq 0.40\%$, $0.0002\% \leqq O \leqq 0.0080\%$, $0.001\% \leqq Al \leqq 0.10\%$, and the balance of Fe and inevitable impurities; has transformation point Ar3 in the range from 750° C. to 850° C., with both ends inclusive; has a mean circle-equivalent diameter of a carbide, which belongs to a circle-equivalent diameter range from 0.1 μm to 3 μm observed in a section of a structure obtained after spherodizing a sample that was heated at a temperature of (Ar3+50° C.) or above and 1,050° C. or below, of 0.25 μm to 0.8 μm, with both ends inclusive; has a Brinell hardness attained after the spherodizing of HB179 to HB235, with both ends inclusive; has a steel cleanliness of (dB+dC)60×400 in the group C inclusion and the group B inclusion specified by JIS G0555 of 0.05% or less; and has a K value defined as Cr(%)−6.8×C(%) of 0.1 to 3.5, both ends inclusive.

FIG.1


L value =21.0
L value =27.0
L value =37.8
L value =14.9
K value =3.5
K value =0.1
Cr
C
13
12
11
10
9
8
7
6
5
0.5 0.6 0.7 0.8 0.9 1 1.1 1.2 1.3 1.4 1.5 1.6 1.7

COLD WORKING DIE STEEL

FIELD OF THE INVENTION

[0001] This invention relates to a cold working die steel used for cold die and structural components processed by forging or pressing in cold working; mechanical components demanding wear resistance; punch and die for cold forging; mold die for high tensile steel sheets; bending dies; cold forging dies; swaging dies; thread rolling dies; punch components; slitter knives; punch dies for lead frames; gauges; deep-drawing punches; bender punches; shear blades; benders for stainless steel; drawing dies; tools for plastic working such as heading; punches for gears; cam components; press punch dies; progressive punch dies; seal plates for soil conveyers; screw components; rotary plates for concrete spraying machines; IC molding dies; precision press mold demanding high dimensional accuracy; and dies used for the above-described applications after being surface-treated by CVD, PVD or TD.

BACKGROUND ART

[0002] SKD11, SKD12 and so forth, which are representative steel types for high-alloy cold dies specified by JIS G4404 have conventionally been used as cold die steel. These cold die steels are subjected to cold working after being subjected to hot working (forging, rolling), and then to annealing, in which the steel is heated to a temperature range from point Ar3 to Ar3+50° C. and then slowly cooled. The hardness obtained after annealing under such annealing conditions falls in the range approximately from HB241 to HB255 on the Brinell hardness basis.

[0003] Japanese Laid-Open Patent Publication "Tokkaihei" No. 6-322439 discloses that the hardness can be lowered as compared with that attained by conventional annealing, by raising the annealing temperature higher than in the conventional process. Although the document describes that the lowering of the hardness can increase the machinability, it is hardly said that the hardness of HV262 to 278 (approximately 250 to 265 on the HB basis) listed in Table 2 is small enough. Moreover, no description is made on the hardness after quench-and-temper, despite a known problem in that annealing carried out at a temperature higher than hardening temperature results in lowering in the hardness after quench and temper than usual.

[0004] In recent years, shorter delivery periods and lower costs in the fabrication process have been more strongly demanded, and there have been increased demands on cold working die steel more easily used in machinability such as post-anneal machinability after annealing or cold workability, in view of achieving near-net-shaping and shortening of the time period for fabricating the structural and mechanical components. With cold tool steel, however, it is hard to achieve a low level of hardness by annealing intrinsically because of the composition thereof.

[0005] Steel having large amounts of coarse carbide are used for applications in particular demanding wear resistance such as dies, tools and mechanical components, in view of the wear resistance, but making too much account of wear resistance inevitably results in degradation of the material characteristics, such as a lowering of the overall toughness. On the other hand, a decrease in the coarse carbide or an addition of a large amount of element enhancing free-cutting properties, such as S, aiming at improving the machinability, lowers the wear resistance required for tool steel. It is to be noted herein that the "coarse carbide (primary carbide)" refers to a carbide having a diameter of approximately 10 μm or larger on a circle-equivalent basis.

[0006] The present invention was conceived taking the above-described problems into account, and an object thereof resides in providing a cold working die steel which can be reduced in its hardness by annealing, and is improved in readiness in the cold workability (forging, pressing and so forth) and machinability (milling, drilling, endmilling processing, grinding and turning).

SUMMARY OF THE INVENTION

[0007] Aiming at solving the aforementioned problems, cold working die steel according to the first aspect of this invention consists essentially of, in % by mass and by both ends inclusive, $0.6\% \leqq C \leqq 1.60\%$, $0.10\% \leqq Si \leqq 1.20\%$, $0.10 \leqq Mn \leqq 0.60\%$, $5.5\% \leqq Cr \leqq 13.0\%$, $0.80\% \leqq Mo + 0.5W \leqq 2.10\%$, $0.10\% \leqq V \leqq 0.40\%$, $0.0002\% \leqq O \leqq 0.0080\%$, $0.001\% \leqq Al \leqq 0.10\%$, and the balance of Fe and inevitable impurities; having transformation point Ar3 in the range from 750° C. to 850° C., with both ends inclusive; having a mean circle-equivalent diameter of a carbide, which belongs to a circle-equivalent diameter range from 0.1 μm to 3 μm observed in a section of a structure obtained after spherodizing a sample heated at a temperature of (Ar3+50° C.) or above and 1,050° C. or below, of 0.25 μm to 0.8 μm, with both ends inclusive; having a Brinell hardness attained after the spherodizing of HB179 to HB235, with both ends inclusive; having a steel cleanliness level of (dB+dC)60×400 in group C inclusion and group B inclusion specified by JIS G0555 of 0.05% or less; and having a K value defined as Cr(%)−6.8×C(%) of 0.1 to 3.5, with both ends inclusive.

[0008] This invention has major features described below.

(1) Lowering of the Hardness After Annealing

[0009] Hardness after annealing is determined mainly by state of distribution of carbide having a diameter ranging from 0.1 μm to 3 μm, with both ends inclusive, on the circle-equivalent basis (referred to as secondary carbide, hereinafter), so that the hardness can be decreased by adjusting the mean circle-equivalent diameter of the carbide to the range from 0.2 μm to 0.8 μm, with both ends inclusive. This range of the mean circle-equivalent diameter corresponds to the enlargement of the secondary carbide. In other words, an absolute amount of the secondary carbide produced by the annealing is the same, so that a larger mean circle-equivalent diameter results in a smaller hardness due to scarceness of the secondary carbide having relatively large sizes.

[0010] On the contrary, a smaller mean circle-equivalent diameter results in a larger hardness by virtue of the denseness of the secondary carbide having relatively small sizes. More specifically, adjustment of the mean circle-equivalent diameter of the secondary carbide in the above-described range makes it possible to obtain a Brinell hardness of as low as HB179 to HB235, with both ends inclusive (conventional steels showed a Brinell hardness of as large as HB241 to HB255 or around), and to distinctively improve the efficiency in machining and cold working.

(2) Control of the Size of the Secondary Carbide by Annealing Conditions

[0011] Size of the secondary carbide is controlled by spherodizing, or keeping the steel heated at a temperature of (Ar3+50° C.) or above and 1,050° C. or below. In more detail, the steel is heated at a temperature (from Ar3+50° C. to a hardening temperature (1,050° C. or around)) higher than the conventional annealing temperature (from Ar3 to Ar3+50° C.) so as to allow more secondary carbides to dissolve into the matrix. The reason why the temperature at which the steel is heated is adjusted to a temperature lower than the hardening temperature (1,050° C. or around) is to avoid lowering of the hardness after quench-and-temper.

[0012] Thereafter, the steel is gradually cooled at a cooling rate slower than 60° C./h to as low as 750° C. or below, in order to allow the dissolved secondary carbide to grow into larger grains (gradual cooling method). Other known treatment methods include the "repetitive heating-and-gradual-cooling method" in which heating and cooling are repeated at least twice within temperature ranges from 650° C. to transformation point Ar1, and from transformation point Ar3 to 1,050° C.; "prolonged annealing method" in which the steel is kept at a temperature lower than Ar3 for a long period of time; and "isothermal transformation method" in which the steel is kept at a constant temperature during the gradual cooling process in the gradual cooling method.

[0013] Any of these methods can successfully control the size of the secondary carbide. Low temperature annealing at a temperature of Ar1 or below before the spherodizing annealing makes it possible to reduce variation in the post-anneal hardness after annealing and to obtain still an even lower hardness. It is to be noted that the above-described spherodized annealing will not largely alter the size and population of the coarse carbide (primary carbide) which affects the wear resistance required for applications such as dies and tools.

[0014] Transformation point "Ar3" herein expresses the A3 transformation point (austenization temperature), wherein "r" means cooling (refroidissement). In the spherodized annealing, the temperature at which the steel is heated is necessarily set higher than that in the conventional process in view of thoroughly dissolving the secondary carbides into the matrix, and the transformation point of Ar3 is necessarily low enough so as to adjust the temperature to the quenching temperature or below. In other words, it is required that there is a large enough difference between the transformation point of Ar3 and the quenching temperature.

[0015] The steel is therefore necessarily adjusted in the composition thereof so as to make transformation point Ar3 fall within the range of 750° C. to 850° C. If the Ar3 is too high only a small difference from the normal quenching temperature (1,050° C. or around) will result, and consequently fail in raising the annealing temperature thereby resulting in only an insufficient dissolution of the secondary carbide (not so different from the conventional annealing). On the other hand, if the Ar3 is too low, a vastly longer duration time for the depositing and growing of the secondary carbide. The annealing temperature herein is determined to a desirable level (Ar3+50° C. to quenching temperature (at around 1,050° C.)), based on results of the measurements of the transformation point Ar3 using an apparatus such as DTA (differential thermal analyzer).

(3) Influence of Oxide-Base Inclusion on Machinability

[0016] Increases in groups B and C (oxide-based ones in particular) inclusions (conforming to JIS G0555) are known to decrease the machinability. These inclusions have extremely high hardness of their own, which exceeds the hardness of the matrix. By coming into contact with these inclusions, tool edges can be chipped and the lifetime of tools can be considerably decreased. Both group B and C inclusions become less affective as the contents of which reduce closer to 0, so that it is necessary, for the purpose of obtaining more sufficient machinability than conventional steel, to adjust the steel cleanliness to $(dB+dC)60\times400\leqq0.05\%$. This cleanliness level can be obtained by adjusting mainly the contents of O and Al within the range described later.

[0017] The following paragraphs will describe reasons for limitations of the individual numerical ranges.

(4) $0.6\%\leqq C\leqq1.60\%$

[0018] C is an essential element for raising the hardness of martensite after quenching. The element forms carbide through binding with carbide-forming elements such as Cr, Mo and V, and thereby make the crystal grain more fine. The carbide also contributes to the improvement of the wear resistance. An addition to an amount of the lower limit or more is necessary in order to realize a hardness after quench and temper of HRC55 or above. On the other hand, the element is added to as much as the upper limit or less, because excessive addition results in excessive content of the carbide, which thereby decreases the toughness.

(5) $0.10\%\leqq Si\leqq1.20\%$

[0019] Si is added as a deoxidizing element. Because the element contributes to the increase in hardness in the high-temperature-temper, it is added to as much as the lower limit or more, so as to obtain the effect. On the other hand, the element is added to as much as the upper limit or less, because excessive addition degrades the hot workability, and the after-quench-and-temper toughness.

(6) $0.10\%\leqq Mn\leqq0.60\%$

[0020] Mn is added as a deoxidizing element. Because the element contributes to the enhancement of the hardenability, and increasing in the hardness and strength, it is added to as much as 0.10% or more. On the other hand, the upper limit of the element is set to 0.60%, because excessive addition degrades the hot workability.

(7) $5.5\%\leqq Cr\leqq13.0\%$

[0021] Cr dissolves into the matrix which raises the hardenability and increases the hardness, and forms carbides which increase the wear resistance. Additions to as much as the lower limit or more are necessary for obtaining these effects. On the other hand, the element is added to as much as the upper limit or less, because excessive addition results in formation of an excessive amount of carbides which decrease the toughness and machinability after quench-and-temper.

(8) $0.80\%\leqq Mo+0.5W\leqq2.10\%$

[0022] Mo and W dissolve into the solid matrix to thereby raise the hardenability and to contribute to increase hardness, and forms carbides to which increase the wear resistance. The elements also have an effect of raising the anti-softening hardness in quench-and-temper. Addition to as much as the lower limit or more, on the Mo-equivalent basis expressed as Mo(%)+0.5W(%), is necessary for obtaining these effects. On the other hand, the element is added to as much as the upper limit or less, because excessive addition decreases the hot workability, toughness and machinability.

(9) 0.10%≦V≦0.40%

[0023] V forms a stable carbide, and thereby effectively prevents the crystal grains from coarsening. The element forms a fine carbide, and thereby contributes to increases in the wear resistance and the hardness. Addition to as much as 0.10% or more is necessary for obtaining these effects. On the other hand, the upper limit is set to 0.40%, because excessive addition increases the carbide content, and thereby decreases the machinability and hot workability.

(10) 0.0002%≦O≦0.0080%, 0.001%≦Al≦0.10%

[0024] O and Al are inevitably contained in the steel. The elements are constituent elements of group B and C inclusions, and large contents of which can decrease the toughness, so that it is necessary to suppress the contents to as much as the upper limit or less. Positive efforts of reducing these elements, although depending on balance with the production cost, makes it possible to maintain a high, stable toughness. Excessive lowering of the contents only results in an increase in the production cost and a saturation of influences exerted on the toughness, so that the elements are added to as much as the lower limit or more.

(11) Transformation Point Ar3 Adjusted to 750° C. to 850° C.

[0025] Transformation point Ar3 adjusted in the above-described range can expand the temperature range ranging from Ar3+50° C., at which spherodizing is effected. The quenching temperature (about 1,050° C.), ensures a sufficient range of annealing temperature allowing the secondary carbides to thoroughly dissolve. An excessively high Ar3, however, narrows the temperature range from Ar3+50° C. to the quenching temperature (about 1,050° C.), and fails to ensure a sufficient range of an annealing temperature. This, as a consequence, extremely reduces the amount of dissolution of the secondary carbides, and fails in obtaining low hardness required for raising machinability. An excessively low Ar3 takes a longer time to allow the secondary carbides to deposit and grow in the process of gradual cooling at a temperature as low as Ar3 or below, and this extremely raises the cost from the industrial viewpoint. It is to be understood that Ar3 can be measured typically by DTA, and defined as being obtained at a cooling rate of 5° C./h or more to 60° C./h, because Ar3 varies depending on conditions of the measurement.

[0026] (12) The mean circle-equivalent diameter of the carbide, which belongs to the circle-equivalent diameter range of 0.1 μm to 3 μm was observed in the section of the structure obtained after spherodizing a sample that was heated at a temperature of (Ar3+50° C.) or above and 1,050° C. or below, adjusted to 0.25 μm or more and 0.8 μm or less.

[0027] The mean circle-equivalent diameter of the carbide is calculated by an image analysis of a polished section of the steel structure. More specifically, a circle-equivalent diameter is calculated for every carbide grain having a circle-equivalent diameter ranging from 0.1 μm to 3 μm which can be seen in a magnified field of view under a scanning electron microscope or an optical microscope, and a mean value of which is determined as the mean circle-equivalent diameter. It is necessary that the observation in the magnified field of view is carried out at least in an area of 1 mm^2 or larger, at randomly selected positions excluding the surface and center portions of the material. Alternatively, it is also allowable to use 20 or more fields of view, when each field contains 20 to 50 carbide grains having a circle-equivalent diameter ranging from 0.1 μm to 3 μm. The carbide having a diameter ranging from 0.1 μm to 3 μm means a carbide (secondary carbide) contributive to the hardness.

[0028] A mean grain size of the carbide belonging this range of less than 0.25 μm results in a high hardness, and fails in obtaining the effect of increasing the machinability (this applies to the case where the conventional style of annealing was carried out). On the other hand, an excessively large mean grain size results in an extremely small number of carbide grains grown during the process of gradual cooling in the annealing, and this makes the regenerative perlite more likely to deposit in the cooling process, and conversely increases the hardness. It is therefore necessary to set the upper limit of the mean circle-equivalent diameter of carbide to 0.8 μm.

(13) Brinell Hardness Attained After Spherodizing of HB179 to HB235

[0029] Adjustment of the Brinell hardness after the spherodizing to HB179 to HB235 makes it possible to obtain the machinability and cold workability superior to those in the prior art. Excessive lowering of the hardness results in a high cost from the industrial point of view, so that a hardness of HB179 or more is enough for the purpose.

(14) Steel Cleanliness in Group B and C Inclusions Specified by JIS G0555 of (dB+dC)60×400≦0.05%

[0030] The class B inclusion (mainly alumina and so forth) refers to grains forming an agglomerate discontinuously arrayed in the working direction, and the group C inclusion (such as granular oxide) refers to grains irregularly dispersed without causing viscous deformation. Excessive amounts of these inclusions decreases the machinability, and a desirable level of machinability can be obtained by adjusting the cleanliness (dB+dC)60×400 of the steel with respect to group B and C inclusions, determined by the test method as specified in JIS G0555, of 0.05% or less.

(15) K Value Expressed by Cr(mass %)−6.8×C(mass %) of 0.1 or More and 3.5 or Less

[0031] K value expresses the amount of Cr solubilized in the matrix at an appropriate quenching temperature. Adjustment within the above range results in the hardness obtained after quench-and-temper almost equivalent to the previous, and therefore makes it possible to adjust the amount of deposition of carbides depending on the wear resistance, toughness and machinability required for the cold working die steel. In contrast, if the K value is out of the above range, it results in only an insufficient amount of the secondary carbide which deposits during tempering and contributes to the hardness, and consequently fails in maintaining the hardness necessary for the cold working die steel. **FIG. 1**

shows a relation between the C content and the Cr content. The straight lines ascending from the lower left towards the upper right in the drawing relate to the K value, and the straight lines descending from the upper left towards the lower right in the drawing relate to the L value described later.

[**0032**] The cold working die steel of this invention can further contain, as steel components, either one of or both of 0.0030%≦N≦0.0500% and 0.001%≦P≦0.040%.

[**0033**] These elements are inevitably contained in the steel. Large contents of these elements decrease the toughness, so it is preferable to control them to as much as the upper limit or below. A positive effort of reducing these elements, in a trade-off manner with the manufacturing cost, makes it possible to maintain a stable and high toughness. It is to be understood that excessive lowering in the contents only results in an increase in cost while allowing an effect on the toughness to saturate, so that it is preferable to control them to the lower limit or above.

[**0034**] The cold working die steel of this invention can further contain, as steel components, any one of, or two or more of steel components selected from 0.01%≦Cu≦1.0%, 0.01%≦Ni≦1.0%, 0.2%≦Co≦1.0% and 0.0003%≦B≦0.010%.

[**0035**] These elements have an effect of increasing the hardenability by dissolving themselves into the matrix. They have also an effect of increasing the toughness by lowering the impact transition temperature, and by consequently preventing the weldability from degrading. Co has an effect of increasing the high temperature strength. Addition to as much as the lower limit or above is preferable in view of obtaining these effects. The elements are added to as much as the upper limit or less, because excessive addition only results in a saturated effect.

[**0036**] The cold working die steel of this invention can further contain, as steel components, any one of, or two or more of 0.001%≦S≦0.20%, 0.005%≦Se≦0.10%, 0.005%≦Te≦0.10%, 0.0002%≦Ca≦0.010%, 0.005%≦Pb≦0.10% and 0.005%≦Bi≦0.10%.

[**0037**] S can be added as an element increasing the free cutting property. Depending on the contents of the carbide-forming elements such as Cr, Mo and V, addition to as much as 0.04% or more is preferable in view of obtaining the effect of increasing the free cutting property. Excessive addition of the element considerably decreases the toughness, or mechanical properties including surface roughness after discharge processing and cutting, so that the upper limit is preferably adjusted to 0.20%. For applications making a great account of machinability, the element is added considering the balance with the mechanical properties. On the other hand, for applications in which a greater account is placed on the mechanical properties rather than on the machinability, the amount of addition of S is set to 0.02% or less, and more preferably to 0.01% or less, considering the balance with the cost for manufacturing. The mechanical properties can be satisfied by adjusting the amount of the addition to 0.01% or more and 0.02% or less for the practical operation. This makes it possible to obtain the S content described in the above.

[**0038**] Also Se, Te, Ca, Pb and Bi can be added for the purpose of increasing machinability. Se and Te can be used as substitutive elements of S in Mn sulfide. Ca improves the machinability by forming a protective film on the surface of a tool during cutting, by forming an oxide or by dissolving itself into Mn sulfide. Pb and Bi segregate in the grain boundary, to thereby lower the grain boundary strength and to improve the machinability. The elements are necessarily added to as much as the lower limits or more in view of obtaining these effects. On the other hand, excessive addition results in degraded mechanical properties, so that the upper limits should be met.

[**0039**] The cold working die steel of this invention can further contain, as the steel components, any one of, or two or more of 0.01%≦Nb≦0.12%, 0.005%≦Ta≦0.10%, 0.005%≦Ti≦0.10%, 0.005%≦Zr≦0.10%, 0.005%≦Mg≦0.10% and 0.005%≦REM≦0.10%.

[**0040**] These elements can be added for the purpose of obtaining an effect of increasing the toughness through fineness of the carbide grains and fineness of the crystal grains. Mg and REM have an effect of increasing the toughness and machinability, through formation of oxides, which contribute to the reduction of the O content and consequently in coarse oxide grains. Addition to as much as the lower limit or above is preferable in view of obtaining these effects. On the other hand, excessive addition results in decreasing in the toughness and weldability, so that the amount of addition is preferably set to the upper limit or less. A single species or two or more species of rare earth metals may be used as REM.

[**0041**] Next, the cold working die steel according to the second aspect may contain, as the steel components, 0.60%≦C≦0.80%, 0.10%≦Si≦1.20%, 0.10%≦Mn≦0.60%, 5.5%≦Cr≦8.5%, 0.80%≦Mo+0.5W≦2.10%, 0.10%≦V≦0.40%, 0.0002%≦Al≦0.0080%. In other words, further limitations are added to C, Si, Cr and Mo, out of the steel components according to the first aspect.

[**0042**] It is essential for cold working die steel die applications, that the toughness and fine machining are particularly required to decrease the coarse carbide. More specifically, it is necessary to avoid as much as possible, the formation of coarse carbides mainly composed of M_7C_3 (where, M represents Cr, Mo or V), by adjusting the contents of C, Si, Cr and Mo within the above-described ranges. The amount of coarse carbide corresponds to 0.01 to 5% in % by mass. Assuming now L value as an index expressing the amount of coarse carbide as Cr(mass %)+15.5×C(mass %), the amount of coarse carbide corresponds to 14.9≦(L value)≦21.0 (see **FIG. 1**).

[**0043**] Next, the cold working die steel according to the third aspect may contain, as the steel components, 0.90%≦C≦1.10%, 0.8%≦Si≦1.20%, 0.10%≦Mn≦0.60%, 7.0%≦Cr≦9.0%, 1.50%≦Mo+0.5W≦2.10%, 0.10%≦V≦0.40%, 0.0002%≦Al≦0.0080%. In other words, further limitations are added to C, Si, Cr and Mo, out of the steel components according to the first aspect.

[**0044**] It is necessary for cold working die steel die applications, that the wear resistance and the toughness must be well-balanced, to ensure a certain amount of coarse carbides. More specifically, the coarse carbides mainly composed of M_7C_3, are formed by adjusting the contents of C, Si, Cr and Mo within the above-described ranges. The amount of coarse carbides corresponds from 5 to 10% in % by mass, and to 21.0≦(L value)≦27.0 (see **FIG. 1**).

[0045] Next, the cold working die steel according to the fourth aspect may contain, as the steel components, 1.40%≦C≦1.60%, 0.10%≦Si≦0.40%, 0.10%≦≦Mn≦0.60%, 11.0%≦Cr≦13.0%, 0.80%≦Mo+0.5W≦1.20%, 0.10%≦V≦0.40%, 0.0002%≦Al≦0.0080% In other words, further limitations are added to C, Si, Cr and Mo, out of the steel components according to the first aspect.

[0046] It is necessary for cold working die steel die applications, where the wear resistance is particularly required, to contain a large amount of coarse carbide. More specifically, large amounts of coarse carbides mainly composed of M_7C_3 are formed by adjusting the contents of C, Si, Cr and Mo within the above-described ranges. The amount of coarse carbide corresponds to 10 to 15% in % by mass, and to 27.0≦(L value)≦37.8 (see **FIG. 1**).

BRIEF DESCRIPTION OF THE DRAWING

[0047] **FIG. 1** is a drawing expressing relations between C content and Cr content (K value, L value).

BEST MODES FOR CARRYING OUT THE INVENTION

[0048] First, 200 kg of each of the inventive and comparative steel materials having compositions listed in Table 1 were melted in a vacuum induction furnace, made into an ingot, and the obtained steel ingot was hot-forged so as to produce a 70 mm×70 mm square rod. The rod was then annealed at the temperature listed in Table 2 (cooling rate: 18° C./h).

[0049] Of the compositions of comparative steels listed in Table 1, those departing from the compositional ranges specified by this invention are indicated by a downward arrow (↓) if they came short of the lower limits, by an upward arrow (↑) if they exceeded the upper limits.

[0050] [Table 1]

TABLE 1

Components (wt %)											
No.		C	Si	Mn	P	S	Cu	Ni	Cr	Mo	W
1	Comparative steel	0.71	0.38	↑0.93	0.028		↑1.32	0.11	7.03	0.84	
2	Inventive steel	1.23	0.53	0.34			0.06	0.43	10.32	1.44	
3	Comparative steel	0.71	0.38	0.37	0.028	0.002	0.09	↑1.55	7.03	0.84	
4	Comparative steel	0.66	0.42	0.32	0.013	0.001	0.23	0.53	10.5	0.32	
5	Inventive steel	0.61	0.95	0.47	0.004	0.063	0.05	0.13	5.7	2.01	
6	Inventive steel	0.78	0.75	0.21	0.035	0.035	0.85	0.53	5.81	2.09	
7	Inventive steel	0.93	0.23	0.15	0.021	0.001	0.34	0.43	6.53	0.82	
8	Inventive steel	0.79	0.35	0.32	0.003	0.23	0.03	8.82	0.93		
9	Inventive steel	0.62	0.11	0.11	0.028	0.058	0.53	0.84	7.53	1.56	
10	Inventive steel	0.72	0.69	0.55	0.013	0.008	0.13	0.08	7.03	1.03	
11	Inventive steel	0.78	1.17	0.59	0.018	0.17	0.25	0.31	6.53	0.81	0.02
12	Inventive steel	0.71	1.18	0.58	0.022	0.008	0.023	0.89	8.2	0.88	0.83
13	Inventive steel	0.83	0.11	0.42	0.006	0.004	0.14	0.67	5.96	1.65	
14	Comparative steel	0.93	0.89	0.31	0.022	↑0.25	0.08	0.33	↑13.94	1.83	
15	Comparative steel	0.99	0.89	0.52	0.012	0.003	0.35	0.46	6.34	1.93	
16	Inventive steel	0.94	0.93	0.41	0.011	0.001	0.02	0.04	6.63	1.84	
17	Inventive steel	1.19	0.83	0.22	0.001	0.14	0.75	0.23	8.32	1.74	0.11
18	Inventive steel	1.07	0.85	0.39	0.013	0.003	0.05	0.13	10.71	1.63	
19	Inventive steel	0.81	0.93	0.18	0.032	0.002	0.13	0.45	8.83	1.99	0.03
20	Inventive steel	0.92	1.05	0.59	0.021	0.095	0.34	0.63	8.21	2.03	
21	Inventive steel	0.88	1.17	0.11	0.009	0.103	0.23	0.09	7.58	1.54	
22	Inventive steel	0.99	1.08	0.58	0.013	0.003	0.02	0.75	9.03	2.08	
23	Inventive steel	0.99	0.42	0.11	0.023	0.38	0.08	0.09	8.25	0.97	
24	Inventive steel	0.86	0.93	0.11	0.025	0.001	0.011	0.98	9.32	1.55	
25	Comparative steel	↑1.83	0.32	0.53		0.001	0.09	0.31	11.95	↓0.43	
26	Comparative steel	1.53	0.13	0.43	0.011	0.001	0.21	0.33	9.31	0.88	0.31
27	Inventive steel	1.23	0.29	0.46	0.018	0.001	0.04	0.08	8.53	0.83	0.22
28	Inventive steel	1.58	0.11	0.23	0.005	0.11	0.32	0.32	11.44	0.95	
29	Inventive steel	1.56	0.18	0.12	0.029	0.002	0.03	0.98	12.98	0.93	0.31
30	Inventive steel	1.44	0.21	0.18	0.003	0.08	0.09	0.75	12.84	1.18	
31	Inventive steel	1.08	0.31	0.22	0.002	0.002	0.21	0.63	10.73	1.09	
32	Inventive steel	1.43	0.37	0.34	0.009	0.083	0.85	0.15	12.59	1.05	0.09
33	Inventive steel	1.23	0.23	0.57	0.028	0.052	0.43	0.44	10.39	1.02	
34	Inventive steel	1.45	0.97	0.36	0.038	0.034	0.88	0.1	12.78	0.76	1.33
35	Inventive steel	1.3	0.29	0.43	0.024	0.27	0.91	0.06	12.01	1.85	

No.	V	Al	O	N	K value	L value	Others
1	0.35	0.028	0.0009		2.202	18.035	
2	0.15	0.093	0.0053		1.956	29.385	
3	↑1.34	0.028	0.0009	0.019	2.202	18.035	
4	0.11	0.033	0.0021	0.011	↑6.012	20.73	
5	0.21	0.008	0.0023	0.015	1.552	15.155	
6	0.39	0.03	0.0053	0.004	0.506	17.9	
7	0.11	0.09	0.0003	0.0033	0.206	20.945	

TABLE 1-continued

	Components (wt %)						
8	0.12	0.053	0.0009	0.0085	3.448	21.065	
9	0.11	0.08	0.0004	0.009	3.314	17.14	
10	0.14	0.032	0.0063	0.013	2.134	18.19	
11	0.33	0.021	0.0078	0.024	1.226	18.62	
12	0.13	0.012	0.0013	0.012	3.372	19.205	B = 0.0032
13	0.22	0.096	0.0043	0.048	0.316	18.825	Zr = 0.022, Ta = 0.07, Mg = 0.09
14	0.22	0.053	0.0031	0.011	↑7.616	28.355	
15	0.32	0.023	0.0039	0.016	↓−0.392	21.685	
16	0.31	0.011	0.0019	0.009	0.238	21.2	
17	0.21	0.022	0.0043	0.0395	0.228	26.765	
18	0.25	0.034	0.0041	0.0312	3.434	27.295	
19	0.33	0.048	0.0077	0.0213	3.322	21.385	
20	0.29	0.028	0.0063	0.0183	1.954	22.47	
21	0.19	0.035	0.0031	0.018	1.596	21.22	
22	0.37	0.059	0.0019	0.031	2.298	24.375	
23	0.18	0.001	0.0002	0.0035	1.518	23.595	Mo = 0.02, Ti = 0.043, REM = 0.05
24	0.39	0.032	0.0079	0.01	3.472	22.65	Ca = 0.0053, Te = 0.026, Bi = 0.024
25	0.34	0.099	0.0009		↓−0.494	40.315	
26	0.25	0.008	0.0019	0.011	↓−1.094	33.025	
27	0.27	0.005	0.0023	0.014	0.166	27.595	
28	0.16	0.008	0.0003	0.0185	0.696	35.93	
29	0.33	0.005	0.0053	0.0045	2.372	37.16	
30	0.23	0.093	0.0005	0.0093	3.048	35.16	
31	0.38	0.053	0.0078	0.023	3.386	27.47	
32	0.11	0.083	0.0015	0.0075	2.866	34.755	
33	0.32	0.053	0.0034	0.0053	2.026	29.455	
34	0.25	0.012	0.0035	0.011	2.92	35.255	Co = 0.36
35	0.33	0.004	0.0031	0.013	3.17	32.16	Pb = 0.09, Se = 0.09

[0051] The inventive steels and comparative steels were subjected to the tests and evaluations below. Results are shown in Table 2.

(a) Surface Analysis and Evaluation of Carbide

[0052] The polished surface of each steel was subjected to image analysis and the mean grain size of the carbide was measured. The image analysis was made on an image observed under a SEM, wherein a total of 1 mm^2 area was observed at an appropriate magnification ranging from 500× to 5,000×. The circle-equivalent diameters were calculated for all carbide grains having a diameter ranging from 0.1 μm to 3.0 μm seen in the field of view, and thereby obtained an average mean value. The polished surface herein was etched with a picric acid-ethanol solution to a depth allowing observation of the carbide grains having a diameter of about 0.1 μm, without causing dropping of the carbide grains.

(b) Amounts of Group B and C Inclusions

[0053] According to the test method specified by JIS G0555, (dB+dC)60×400 was measured.

(c) Machinability Test

[0054] A test piece was cut out from each of the manufactured inventive steels and comparative steels, and subjected to the machinability test.

Conditions for Endmill Processing Test

[0055] Tool: carbide solid endmill (ϕ=10 mm), six-flute

[0056] Cutting speed: 120 m/min

[0057] Feed: 0.06 mm/rev

[0058] Cutting width: 0.5 mm, 10 mm in height

[0059] Lubricant: air blow

[0060] Cutting length: up to 60,000 mm

[0061] Judgment: marked with ○ if the tool caused no breakage, and marked with x if the tool caused breakage or sparking during the cutting.

(c) Cold Workability

[0062] Test pieces measuring 12×18 mm were cut out from each of the inventive steels and the comparative steels, and pressed by a single stroke to 60% height of the test piece using a 600-t hydraulic press machine. Ten pressed test pieces of the individual steels were observed, and the number of test pieces causing breakage was found.

(e) Maximum Hardness

[0063] Hardness was measured using a Rockwell C scale, under varied annealing conditions in the quench-and-temper.

(f) Specific Wear

[0064] Specific wear was measured using a pin-on-disk friction and wear tester. Two 8-mm-diameter pins were cut out from the individual manufactured inventive steels and the comparative steels. A disk was cut out from S45C. The inventive steels and the comparative steels were subjected to quench-and-temper under which the maximum hardness can be attained. Test conditions included a slipping rate of 1.6 m/s, and a press load of 10.5 kgf, with no lubricant. The weight of the pins was measured before and after the test, and loss of weight by wear was measured. The specific wear of the inventive steels and the comparative steels was evaluated, assuming that the weight loss by the wear of comparative steel was 1 as one.

(g) Charpy Impact Value

[0065] A 10R-notched Charpy test piece was cut out from each of the manufactured inventive steels and the comparative steels. The direction of the test pieces was aligned to the longitudinal direction of the material. Under annealing conditions yielding the maximum hardness, the test was carried out according to the method described in JIS Z2242. The test was carried out under room temperature.

[0066] [Table 2]

TABLE 2

No.		Ar3 temperature (° C.)	Mean circle-equivalent diameter of the carbide (μm)	Inclusion dB + dC	Annealing temperature (° C.)	After-SA hardness (HB)	Maximum hardness (HRC)	Cold work-ability	Machin-ability	Specific wear	Charpy impact value (J/cm2)
1	Comparative steel	↓ 740	↓ 0.21	0.005	↓ 750	↑ 269	60.3	x8	x	1	53
2	Inventive steel	793	0.71	0.002	980	204	63.2	○	○	0.32	21
3	Comparative steel	↓ 733	↑ 1.53	↑ 0.41	↑ 1140	↓ 170	60.4	○	x	1.03	46
4	Comparative steel	831	0.53	0.003	950	204	54.3	○	○	5.93	53
5	Inventive steel	805	0.45	0.001	970	212	61.3	○	○	0.92	63
6	Inventive steel	822	0.58	0.034	1020	208	63.3	○	○	0.93	68
7	Inventive steel	803	0.38	0.027	960	198	63.5	○	○	0.89	73
8	Inventive steel	755	0.35	0.046	960	199	62.9	○	○	0.93	58
9	Inventive steel	790	0.26	0.003	970	203	64.2	○	○	0.89	66
10	Inventive steel	809	0.44	0.002	970	203	63.8	○	○	0.88	67
11	Inventive steel	833	0.58	0.011	990	185	62.87	○	○	0.84	93
12	Inventive steel	813	0.65	0.001	1030	204	62.7	○	○	0.93	81
13	Inventive steel	836	0.28	0.006	1030	233	62.9	○	○	0.99	88
14	Comparative steel	↑ 876	0.39	↑ 0.39	970	226	51.1	○	x	6.33	67
15	Comparative steel	843	0.67	0.008	950	193	53.2	○	○	6.29	93
16	Inventive steel	848	0.52	0.003	990	198	62.5	○	○	0.63	43
17	Inventive steel	845	0.78	0.048	990	183	64.3	○	○	0.55	44
18	Inventive steel	833	0.47	0.036	990	195	64.1	○	○	0.59	48
19	Inventive steel	828	0.36	0.021	930	199	64.8	○	○	0.63	53
20	Inventive steel	773	0.31	0.012	840	225	63.8	○	○	0.73	41
21	Inventive steel	819	0.63	0.001	930	203	63.7	○	○	0.72	39
22	Inventive steel	835	0.65	0.003	980	211	63.2	○	○	0.72	46
23	Inventive steel	832	0.71	0.007	890	191	62.8	○	○	0.73	52
24	Inventive steel	825	0.68	0.001	930	200	62.7	○	○	0.72	37
25	Comparative steel	↑ 883	↓ 0.11	0.002	↓ 900	↑ 266	48.7	x10	x	3.14	11
26	Comparative steel	817	0.73	0.004	980	213	51.3	○	○	3.82	13
27	Inventive steel	795	0.71	0.002	890	200	62.7	○	○	0.32	19
28	Inventive steel	808	0.68	0.043	1000	201	63.3	○	○	0.31	23
29	Inventive steel	813	0.57	0.007	1000	205	63.2	○	○	0.46	22
30	Inventive steel	803	0.55	0.011	940	209	64.7	○	○	0.49	28
31	Inventive steel	755	0.49	0.028	920	205	62.1	○	○	0.28	27
32	Inventive steel	761	0.68	0.032	990	217	61.8	○	○	0.38	17
33	Inventive steel	783	0.73	0.003	910	218	63.3	○	○	0.37	19
34	Inventive steel	796	0.41	0.006	870	231	63.6	○	○	0.31	20
35	Inventive steel	807	0.29	0.007	860	223	64.4	○	○	0.45	29

[0067] As is known from Table 2, comparative steel 1, having a composition departing from the compositional ranges specified by this invention, showed an extremely lowered Ar3 temperature. The steel annealed under conventional annealing conditions failed to fully solubilize the carbide into solid, and failed in allowing the carbide to grow larger under gradual cooling, so that the carbide became smaller in size, and the steel became harder. The steel was consequently poor in the cold workability, showing cracks in 8 out of ten test pieces.

[0068] Comparative steel 3, having a composition departing from the compositional ranges specified by this invention, showed an extremely lowered Ar3 temperature. Too high a temperature in the quench-and-temper resulted in an extremely lowered hardness, increased ductility of the material, and conversely degraded machinability, although the cold workability was judged as desirable by virtue of a large carbide size and a considerably lowered hardness.

[0069] Comparative steel 4 showed a K value largely departing from the inventive range, despite having a composition within the compositional ranges specified by this invention. The steel therefore failed in achieving a maximum hardness of as large as HRC60 or above after annealing by the quench-and-temper, and failed in obtaining a level of hardness required for cold working die steel. The low hardness also resulted in a large specific wear. Comparative steels 14, 15, 25 and 26, again having K values departing from the inventive range, also resulted in small maximum hardness and larger specific wear.

1. A cold working die steel consisting essentially of, in % by mass, $0.6\% \leqq C \leqq 1.60\%$, $0.10\% \leqq Si \leqq 1.20\%$, $0.10\% \leqq Mn \leqq 0.60\%$, $5.5\% \leqq Cr \leqq 13.0\%$, $0.80\% \leqq Mo + 0.5W \leqq 2.10\%$, $0.10\% \leqq V \leqq 0.40\%$, $0.0002\% \leqq O \leqq 0.0080\%$, $0.001\% \leqq Al \leqq 0.10\%$, and the balance of Fe and inevitable impurities;

having transformation point Ar3 in the range of from 750° C. to 850° C., both ends inclusive;

having a mean circle-equivalent diameter of a carbide, which belongs to a circle-equivalent diameter range from 0.1 μm to 3 μm observed in a section of a structure obtained after spherodizing a sample that was heated at a temperature of (Ar3+50° C.) or above and 1,050° C. or below, of 0.25 μm to 0.8 μm, with both ends inclusive;

having a Brinell hardness attained after the spherodizing of HB179 to HB235, with both ends inclusive;

having a steel cleanliness of (dB+dC)60×400 in the group C inclusion and the group B inclusion specified by JIS G0555 of 0.05% or less; and

having a K value defined as Cr(mass %)−6.8×C(mass %) of 0.1 to 3.5, with both ends inclusive.

2. The cold working die steel as claimed in claim 1, wherein the steel components are 0.60%≦C≦0.80%, 0.10%≦Si≦1.20%, 0.10%≦Mn≦0.60%, 5.5%≦Cr≦8.5%, 0.80%≦Mo+0.5W≦2.10%, 0.10%≦V≦0.40%, 0.0002%≦O≦0.0080% and 0.001%≦Al≦0.10%.

3. The cold working die steel as claimed in claim 1, wherein the steel components are 0.90%≦C≦1.10%, 0.8%≦Si≦1.20%, 0.10%≦Mn≦0.60%, 7.0%≦Cr≦9.0%, 1.50%≦Mo+0.5W≦2.10%, 0.10%≦V≦0.40%, 0.0002%≦O≦0.0080% and 0.001%≦Al≦0.10%.

4. The cold working die steel as claimed in claim 1, wherein the steel components are 1.40%≦C≦1.60%, 0.10%≦Si≦0.40%, 0.10%≦Mn≦0.60%, 11.0%≦Cr≦13.0%, 0.80%≦Mo+0.5W≦1.20%, 0.10%≦V≦0.40%, 0.0002%≦O≦0.0080% and 0.001%≦Al≦0.10%.

5. The cold working die steel as claimed claim 1, further containing, as the steel component, either one of or both of 0.0030%≦N≦0.0500% and 0.001%≦P≦0.040%.

6. The cold working die steel as claimed in claim 1, further containing any one of, or two or more of steel components selected from 0.01%≦Cu≦1.0%, 0.01%≦Ni≦1.0%, 0.2%≦Co≦1.0% and 0.0003%≦B≦0.010%.

7. The cold working die steel as claimed claim 1, further containing any one of, or two or more of steel components selected from 0.001%≦S≦0.20%, 0.005%≦Se≦0.10%, 0.005%≦Te≦0.10%, 0.0002%≦Ca≦0.010%, 0.005%≦Pb≦0.10% and 0.005%≦Bi≦0.10%.

8. The cold working die steel as claimed claim 1, further containing any one of, or two or more of steel components selected from 0.01%≦Nb≦0.12%, 0.005%≦Ta≦0.10%, 0.005%≦Ti≦0.10%, 0.005%≦Zr≦0.10%, 0.005%≦Mg≦0.10% and 0.005%≦REM≦0.10%.

9. The cold working die steel as claimed in claim 1, wherein the spherodizing comprises keeping the steel heated, and cooling the steel to as low as 750° C. or lower at a cooling rate slower than 60° C./h.

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