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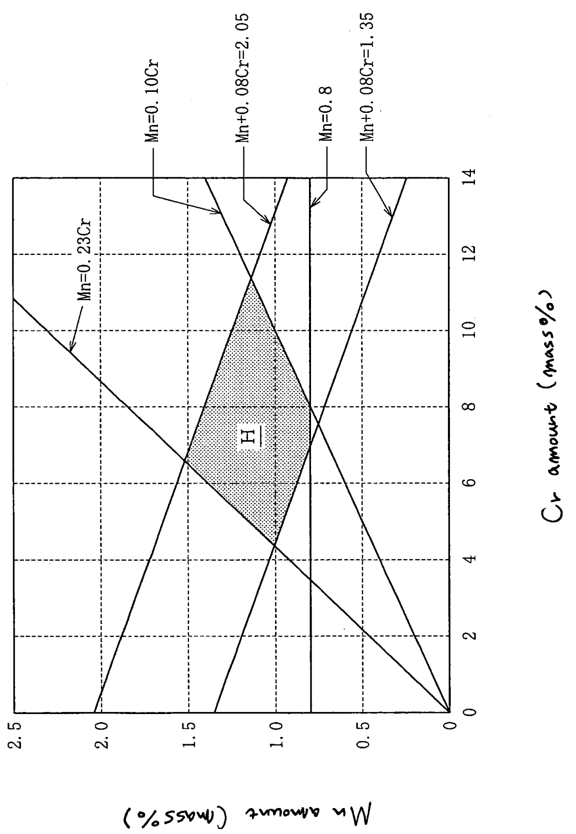
(54) Free-cutting alloy tool steel

(57) The present invention provides a free-cutting alloy tool steel containing, in terms of mass%:
C: from 0.50 to 0.90%,
Si: from 0.50 to 2.20%,
Mn: 0.8% or more,
Mn+0.08Cr: from 1.35 to 2.05%,
Ni: from 0.01 to 0.30%,
Mo+0.5W: from 0.01 to 0.50%,
V: from 0.01 to 0.15%,
S: from 0.03 to 0.15%,

with the balance being Fe and unavoidable impurities, in which the contents of Mn and Cr satisfy the following relationship: Mn/Cr: from 0.10 to 0.23, and the contents of Mo, W and Mn satisfy the following relationship: (Mo+0.5W)/Mn: 0.55 or less.

Fig. 1



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Description

FIELD OF THE INVENTION

[0001] The present invention relates to a free-cutting alloy tool steel. More specifically, the present invention related to a free-cutting alloy tool steel which is particularly prevented from heat treatment deformation by quenching as well as deformation by machining.

[0002] The objective products of the present invention include a cold mold used for the processing by forging or a progressive die press in cold working, and a machine structural member.

[0003] Examples of the cold mold include a block punch, a button die, a pilot punch, a straight punch, a drawing punch, a drawing die, a bending punch/die, a punch-type cutter/roll-type cutter, a thread or groove rolling type, a forging type, a punching member/die for gears, and a swaging die.

[0004] Examples of the machine structural member include a base plate, a guide plate, a spacer, a stripper, a screw plug, a retainer, a guide bush, a dowel bush, a stripper guide, a knock out pin, a shank, a guide post, a fixing key, a plastic forming tool, a screw member, a cam component, a seal plate and gauges.

[0005] The mold or structural member in uses above also includes a cold mold or structural member subjected to a surface treatment such as CVD treatment, PVD treatment, TD treatment and nitridation, or a surface modification such as shot peening.

BACKGROUND OF THE INVENTION

[0006] Conventionally, a carbon tool steel, an alloy tool steel with a small added amount of alloy elements, a cold die steel having added thereto a large amount of Cr, or the like has been used as a tool steel.

[0007] The carbon tool steel or alloy tool steel is disadvantageously poor in the hardenability due to a small added amount of the alloy elements.

[0008] In such a tool steel, a large amount of Mn is added with an attempt to enhance the hardenability. However, while Mn is an effective element of most enhancing the hardenability, if a large amount of Mn is added, a large amount of retained austenite remains after quenching. Therefore, addition of Mn is naturally limited and Mn cannot be added above a certain amount.

[0009] For this reason, conventional tool steels in which the hardenability is enhanced mainly by the addition of Mn, such as carbon tool steel and alloy tool steel, are originally insufficient in hardenability.

[0010] Accordingly, rapid cooling such as water cooling or oil cooling is inevitable when quenching the steel and in this case, a great temperature difference between the surface and the inside of a product or between the sites differing in the wall thickness of a product is produced during cooling due to a difference in the cooling rate, giving rise to significant deformation (heat treatment deformation) associated with quenching (heat treatment).

[0011] Because of these problems, the carbon tool steel or alloy tool steal cannot be applied to a large mold or the like, and the objective product is limited to a small article of 30 mm or less in thickness.

[0012] On the other hand, the cold die steel is sufficient in the hardenability due to a large added amount of the alloy elements.

[0013] In the cold die steel, a large amount of Cr is generally added as an element for enhancing the hardenability.

[0014] With the same added amount, Cr produces a smaller effect of enhancing the hardenability than Mn, but Cr can be added in a large amount and consequently, the hardenability of the cold die steel is by far higher than that of the carbon tool steel or alloy tool steel in which only Mn is added.

[0015] Accordingly, gradual cooling is sufficient as the cooling rate at the quenching, and material deformation due to the above-described heat treatment applied to the carbon tool steel or alloy tool steel can be inhibited.

[0016] However, in the case of a cold die steel, a large amount of carbide is precipitated by the addition of Cr in a large amount for enhancing the abrasion resistance. Therefore, when the cold die steel is subjected to machining such as cutting and grinding, the carbide harder than the base material abrades the cutting edge of a cutting tool or the grinding stone.

[0017] In such a case, as the amount of carbide is larger, abrasion of the blade edge or grinding stone is more promoted and the resistance of a material against working becomes larger, making it difficult to work upon the material.

[0018] This means that a large stress is imposed on the material during working, and due to the large stress remaining in the material at the completion of working, the material is entirely or locally deformed.

[0019] That is, in the case of a cold die steel where a large amount of Cr is added to precipitate a large amount of carbide, although heat treatment deformation during quenching becomes small owing to high hardenability, there is a problem that large deformation occurs when machining is performed.

[0020] Incidentally, the art related to the present invention includes those disclosed in the following Patent Documents 1, 2 and 3.

[0021] Patent Document 1 discloses an invention related to "Cold Tool Steel for Flame Hardening", Patent Document 2 discloses an invention related to "Cold Tool Steel Having Constant Strain by Heat Treatment and Method For Producing Cold Tool Using the Same", and Patent Document 3 discloses an invention related to "Cold Tool Steel with Excellent Machinability", but all of these inventions differ in the technical idea from the present invention. Accordingly, working examples falling in the component range of the present invention are not found in all of the publications above, and these are an invention different from the present invention.

Patent Document 1 : JP-A-11-131182 (the term "JP-A" as used herein means an "unexamined published Japanese patent application")
Patent Document 2 : JP-A-2002-167644
Patent Document 3 : JP-A-2001-234278

SUMMARY OF THE INVENTION

[0022] Under these circumstances, the present invention has been made with an aim to provide a free-cutting alloy tool steel ensuring that both the material deformation due to heat treatment at quenching and the material deformation due to machining are inhibited and hardness necessary as a cold mold or a machine structural component is obtained.
[0023] Namely, the present invention provides the following items.

1. A free-cutting alloy tool steel comprising, in terms of mass%,
C: from 0.50 to 0.90%,
Si: from 0.50 to 2.20%,
Mn: 0.8% or more,
Mn + 0.08Cr: from 1.35 to 2.05%,
Ni: from 0.01 to 0.30%,
Mo+0.5W: from 0.01 to 0.50%,
V: from 0.01 to 0.15%, and
S: from 0.03 to 0.15%,
with the balance being Fe and unavoidable impurities,
wherein the contents of Mn and Cr satisfy the following relationship:
Mn/Cr: from 0.10 to 0.23, and
the contents of Mo, W and Mn satisfy the following relationship:
(Mo+0.5W)/Mn: 0.55 or less.
(In the above, the chemical symbol for each element indicates the content (mass%) of each element; the same applied to the following items.)
2. The free-cutting alloy tool steel according to item 1, which further contains Ca and O in amounts of, in terms of mass%,
Ca: from 0.0001 to 0.0100%, and
O: 0.0100% or less.
3. The free-cutting alloy tool steel according to item 1 or 2, which further contains, in addition to S, one or two combinations of, in terms of mass%,
Se+Te: from 0.01 to 0.15%, and
Pb+2Bi: from 0.01 to 0.15%.
4. The free-cutting alloy tool steel according to any one of items 1 to 3, which further contains one or more elements ofNb, Ta, Ti and Zr in an amount of, in terms of mass%,
Nb+Ta+Ti+Zr: from 0.01 to 0.15%.
5. The free-cutting alloy tool steel according to any one of items 1 to 4, which is used after being quenched at a temperature of 1,000 to 1,050°C.

BRIEF DESCRIPTION OF THE DRAWINGS

[0024]

Fig. 1 is a view showing the relationship between the Cr amount and the Mn amount in the alloy tool steel of the present invention.
Fig. 2 is a view showing the effect of (Mo+0.5W)/Mn on the quenching/tempering hardness.

BEST MODE FOR CARRYING OUT THE INVENTION

[0025] The present invention has characteristic features that high hardenability of an alloy tool steel is ensured owing to a cooperative action between the action brought about by the addition of Mn and the action brought about by the addition of Cr as well as the added amount of Cr is reduced by virtue of the hardenability enhancing effect resulting from addition of Mn, thereby suppressing the formation of carbide and improving the worsening of machinability due to carbide; and that although hardness in the quenched and tempered state is usually reduced by the addition of Mn, the required hardness is maintained owing to decrease in the added amount of Mo.
[0026] More specifically, as main characteristic features, Mn+0.08Cr is added in a range of 1.35 to 2.05% based on the premise of adding Mn in an amount of 0.8% or more, the ratio of Mn/Cr is set to from 0.1 to 0.23 so as to bring a balance between the added amount of Mn and the added amount of Cr, and further, the ratio of (Mo+0.5W)/Mn is set to 0.55 or less so as to bring a balance between the added amount of Mn and the added amount of (Mo+0.5W).
[0027] The material deformation caused by a heat treatment at the quenching can be suppressed by ensuring sufficient hardenability as in the conventional cold die steel. In this case, the added amount of alloy elements is preferably increased.
[0028] On the other hand, the material deformation caused by machining can be suppressed by reducing the amount of carbide. That is, in terms of material deformation caused by machining, the added amount of alloy elements is preferably reduced.
[0029] These requirements contradict each other, but this problem can be overcome by considering the additive alloy elements separately between elements forming a carbide and elements not contributing to the formation of a carbide.
[0030] Main examples of the elements forming a carbide include C, Cr, Mo, W and V and accordingly, the amounts of such elements are preferably reduced as much as possible.
[0031] On the other hand, main examples of the elements not contributing to the formation of a carbide include Si, Mn and Ni and accordingly, the amounts of such elements are preferably increased as much as possible.
[0032] Consequently, it becomes important to replace Cr added in a large amount in the conventional cold die steel with Mn.
[0033] In addition, it is important to add Mo, W and V as little as possible.
[0034] However, since a hardness of HRC 58 or more is necessary as a cold mold or a machine structural component, C must be added in an amount of 0.50% or more.
[0035] The present invention has been accomplished based on such ideas or findings.
[0036] Fig. 1 shows the relationship between the added amount of Cr and the added amount of Mn in the alloy tool steel of the present invention. In Fig. 1, the region H is the region for the added amounts of Cr and Mn in the present invention.
[0037] According to the present invention, not only the deformation due to a heat treatment at the quenching of an alloy tool steel but also the deformation due to remaining of a stress at the machining can be reduced.
[0038] In addition, according to the present invention, the added amount of Cr that is an expensive alloy element can be reduced to allow for the material cost down and also, the machining is facilitated to bring about reduction in the cost required for working, so that a mold or the like can be produced at a low cost with high effects.
[0039] According to the present invention, when Ca and O are contained each in a predetermined amount according to item 2 above, machinability of the alloy tool steel can be more enhanced.
[0040] Furthermore, when Se+Te or Pb+2Bi are added according to item 3 above, the machinability can be more enhanced.
[0041] Also, when one or more elements ofNb, Ta, Ti and Zr are added according to item 4 above, by virtue of the pinning effect on grains by a carbide, a nitride or the like of such an element, decrease in the amount of carbide due to reduction of the added amount of Cr can be compensated for and the grains can be prevented from coarsening.
[0042] Incidentally, for ensuring the hardenability, it is useful to increase the amount of an element that dissolves at the quenching temperature.
[0043] Accordingly, the quenching temperature is preferably set to a quenching temperature of 1,000°C or more (and 1,050°C or less).
[0044] In other words, it is preferred to establish a component system premised on use after quenching at such a high temperature.
[0045] The quenching at the temperature above also has the following meaning.
[0046] Conventionally, a steel in which Cr is added in a predetermined amount and which is quenched at a quenching temperature of 1,000 to 1,050°C is a quantitatively predominant steel as a tool steel, and accordingly, a heat treatment furnace for quenching is also premised on quenching at such a temperature, that is, a furnace for quenching at 1,000 to 1,050°C is used in general.
[0047] If the quenching temperature is less than the temperature above, equipment therefor needs to be installed and in turn, the cost for a quenching treatment rises.
[0048] When the proper quenching temperature of the material is from 1,000 to 1,050°C, a heat treatment furnace

need not be newly installed and the quenching treatment can be performed at a low cost as is conventionally done.

[0049] The reason for limiting each chemical component used in the present invention is described in detail below. Incidentally, the unit of the component ratio is mass percent. Herein, in the present specification, all the percentages defined by mass are the same as those defined by weight, respectively.

C: from 0.50 to 0.90%

[0050] C needs to be added according to the required hardness so as to bring about martensite formation at the quenching and enhance the hardness. For obtaining a hardness ofHRC 58 or more, at least 0.50% or more of C needs to be added. However, if the added amount is too large, the amount of carbide proportionally increases. Accordingly, the added amount thereof needs to be 0.90% or less. From the above-described standpoint, the added amount thereof is preferably from 0.65 to 0.80%.

Si: from 0.50 to 2.20%

[0051] Si solid dissolves to produce an effect of enhancing the martensite hardness. Since this element enhances the hardenability without forming any , it is added in an amount of 0.50% or more. The added amount thereof is set to 2.20% or less, because if it is too large, a ferrite is produced and the quenching hardness decreases.

Mn: ≥ 0.8%

[0052] Mn is an element that effectively enhances the hardenability. In order to ensure the hardenability as an alternative for Cr, Mo, W and V, this element must be added in an amount of 0.8% or more.

Mn/Cr: from 0.10 to 0.23

[0053] In order to reduce the amount of carbide and ensure the hardenability, it is preferred to raise the proportion of Mn. If the above ratio is less than the lower limit, the amount of carbide is too large and the strain generated due to working cannot be sufficiently decreased, whereas if it exceeds the upper limit, the amount of Mn becomes excessively large and retained austenite is produced in a large amount, failing in ensuring the hardness. Also, if the above ratio exceeds the upper limit, the amount of Cr becomes too small and therefore, insufficient hardenability results.

Mn+0.08Cr: from 1.35 to 2.05%

[0054] The hardenability is more enhanced as the total added amount of Mn+0.08Cr is larger, but if the total added amount thereof is excessively large, retained austenite is produced in a large amount and the hardness cannot be ensured, whereas if it is too small, insufficient hardenability results. Incidentally, the coefficient of 0.08 of Cr indicates the contribution ratio of Cr to the hardenability based on Mn.

Ni: from 0.01 to 0.30%

[0055] Ni has the same effect as Mn. In order to compensate for hardenability assumed by Mn, Ni is added in an amount of 0.01% or more. The added amount thereof is 0.30% or less, because if it is excessively large, the amount of retained austenite increases and the hardness decreases.

Mo+0.5W: from 0.01 to 0.50%

[0056] Mo and W have the same effect. The effect of W is half of the effect of Mo and therefore, the coefficient is 0.5. Since the alloy tool steel comes to have nearly sufficient hardenability by the addition of Mn and Cr, these elements should not be preferably added. However, their addition is required in view of hardness and these must be added in an amount of 0.01%. The added amount thereof is 0.50% or less, because if it is excessively large, the amount of unnecessary carbide increases.

(Mo+0.5W)/Mn: ≤ 0.55

[0057] The addition of Mo+0.5W in a large amount also causes the following problems.

[0058] In the present invention, Mn is added in a large amount of 0.8% or more. With such addition of Mn in a large amount, if the added amount of Mo+0.5W is excessively large, the Ms point or Mf point lowers too much to reduce the hardness in the quenched and tempered state and a hardness of HRC 58 or more cannot be obtained. Accordingly, for obtaining a hardness ofHRC 58 or more, in the present invention, the ratio of (Mo+0.5W)/Mn is set to 0.55 or less.

[0059] Fig. 2 shows the relationship between (Mo+0.5W)/Mn and the quenching/tempering hardness.

[0060] The results shown in Table 2 are obtained when the steel components are C: from 0.60 to 0.75%, Si: from 0.96 to 1.53%, Mn: from 0.81 to 1.53%, Cr: from 6.65 to 7.95%, Mn/Cr: from 0.12 to 0.21, Mn+0.08Cr: from 1:36 to 1.98%, Ni: from 0.15 to 0.16%, Mo: from 0.001 to 2.52%, (Mo+0.5W)/Mn: from 0.005 to 3.11, V: from 0.02 to 0.09%, and S: 0.05%, with the balance being Fe, that is, components specified in the item 1 above except for (Mo+0.5W)/Mn, and for examining the effect of (Mo+0.5W)/Mn, the value thereof is variously changed to examine the effect.

[0061] In Fig. 2, the relationship between (Mo+0.5W)/Mn and the quenching/tempering hardness is specifically determined as follows.

[0062] A steel having the composition above is melted in a vacuum induction furnace to produce 50 kg of an ingot, and the ingot is subjected to soaking at 1,160°C for 10 hours and then forged at a temperature between 900°C and 1,160°C into a square bar of 45 mm × 45 mm × 1,500 mm.

[0063] The tool steel in the square bar state is subjected to a spheroidizing annealing treatment of performing gradual cooling from 900°C at a cooling rate of 20°C/h, and the material after heat treatment is cut and worked into dice of about 20 mm × 20 mm × 20 mm.

[0064] These specimens are heated at 1,030°C for 30 minutes or more, quenched by oil cooling, and then tempered by heating at 180°C for 60 minutes or more.

[0065] After the completion of the heat treatment, scale is removed by grinding and then, the hardness of the specimen is measured.

[0066] Fig. 2 is a view showing this hardness after quenching/tempering with respect to (Mo+0.5W)/Mn.

[0067] In the results of Fig. 2, the main components are within the scope of claim of the present invention, nevertheless, the effect of (Mo+0.5W)/Mn is outstanding.

[0068] It is seen from the results of Fig. 2 that for obtaining a hardness ofHRC 58 or more required of a cold mold or the like, (Mo+0.5W)/Mn must be 0.55 or less.

[0069] This is because within the composition range of the present invention, if Mo or W is excessively added, an untransformed retained austenite structure is increased at the quenching and a hardness cannot be obtained.

[0070] On the other hand, if the added amount of Mo or W is decreased too much, this generally causes reduction of quenching/tempering hardness or reduction of hardenability. However, in the present invention, the added amounts of components such as C, Mn and Cr are specified so that sufficient quenching/tempering hardness can be obtained.

[0071] In terms of hardenability, necessary added amounts are also specified particularly as defined for Mn+0.08Cr.

V: from 0.01 to 0.15%

[0072] V is an element having the same effects as Mo and W and in the present invention, this element is added in the range of 0.01 to 0.15%.

S: from 0.03 to 0.15%

[0073] S binds with Mn to form an MnS compound. This binding brings about enhancement of cutting or grinding machinability. However, if the added amount thereof is less than 0.03%, the enhancing effect cannot be obtained, whereas even if this element is added in excess of 0.15%, the effect is saturated. For these reasons, the upper limit thereof is set to 0.15%.

Ca: from 0.0001 to 0.0100%

[0074] When Ca is added in combination at the time of adding S, the effect of enhancing the machinability is increased. This is because Ca oxide has an effect of protecting a tool. In order to sufficiently form Ca oxide, addition in an amount of 0.0001% or more is necessary. Even if added in excess of 0.0100%, the effect is saturated. Therefore, this is the upper limit.

O: ≤ 0.0100%

[0075] This is an element unavoidably contained in the steel. For forming Ca oxide, O in an amount of 0.0100% or less is necessary.

Se+Te: from 0.01 to 0.15%, Pb+2Bi: from 0.01 to 0.15%

[0076] These elements all are an element that enhances the cutting or grinding machinability. Depending on the scrap used as the raw material, these elements are sometimes added in large amounts and therefore, can be utilized as an alternative to the addition of S. In order to obtain the machinability enhancing effect by the addition of these elements, the added amounts of these elements need to be more than the lower limits as defined above. However, even if added in excess of the upper limits as defined above, the effect is saturated.

Nb+Ta+Ti+Zr: from 0.01 to 0.15%

[0077] These elements all have an effect of forming a carbide or a nitride and preventing coarsening of the grains at the quenching and holding temperature. In the present invention, the addition of Cr, Mo, W and V is reduced as much as possible and therefore, the amount of carbide becomes small. As a result, coarsening of the grains readily occurs. For the purpose of preventing the grains from coarsening and suppressing the reduction of toughness, these elements may be added in a total amount of 0.01% or more. However, even if added in excess of the upper limit of 0.15%, the effect is saturated.

[0078] In this regard, with regard to each element contained in the steel of the invention, according to an embodiment, the minimal amount thereof present in the steel is the smallest non-zero amount used in the Examples of the developed steels as summarized in Table 1. According to a further embodiment, the maximum amount thereof present in the steel is the maximum amount used in the Examples of the developed steels as summarized in Table 1.

Quenching temperature: from 1,000 to 1,050°C

[0079] The quenching temperature of a carbon tool steel or a special tool steel (corresponding to SK or SKS) is less than 1,000°C and therefore, the amount of solid-dissolved elements is small, giving rise to poor hardenability. The quenching temperature of a cold die steel (corresponding to SKD) is 1,000°C or more and the amount of solid-dissolved elements increases. For ensuring the hardenability, a quenching temperature of 1,000°C or more is preferred. However, if heated at a temperature in excess of 1,050°C, low toughness results due to coarsening of the grain diameter. Therefore, a temperature not more than that temperature is preferred.

Examples

[0080] The components shown in Table 1 in an amount of 120 kg were melted in a vacuum induction furnace, and the melt was cast using an ingot case of ϕ 250 mm × 450 mm. The ingot was heated and held at 1,150 to 1,200°C and then forged into a 65 mm square form. After the forging, spheroidizing annealing was performed to give a low hardness ofHRC 25 or less.

[0081] This forged material was cut into a predetermined size required for each test. After the cutting, the material was worked into each specimen and heat-treated at the quenching/tempering temperature shown in Table 2. The hardness after this heat treatment is also shown in Table 2 (when parenthesized, hardness at the quenching temperature in the parenthesis is indicated). Further, as for the evaluation of hardenability and the drill machinability, the test was performed in the spheroidizing annealed state.

[0082] Incidentally, evaluation tests of the respective properties shown in Table 2 were performed as described later.

Table 1

		C (%)	Si (%)	Mn (%)	Cr (%)	Mn/Cr	Mn+ 0.08Cr (%)	Mo (%)	W (%)	(Mo+0.5W) /Mn	Ni (%)	V (%)	S (%)	Ca (%)	O (%)	Se+Te (%)	Pb+2Bi (%)	Nb+Ta+Ti+Zr (%)
Steel of Invention	1	0.87	1.32	1.04	10.1	0.10	1.85	0.08	0.01	0.08	0.09	0.09	0.048					Nb:0.07
	2	0.6	0.63	1.28	8.7	0.15	1.98	0.02	0.02	0.02	0.01	0.01	0.035	0.0078	0.0081			
	3	0.69	0.75	0.89	8.9	0.10	1.60	0.46	0.03	0.53	0.17	0.12	0.144					
	4	0.72	0.91	1.2	7.8	0.15	1.82	0.26	0.13	0.27	0.07	0.07	0.072					
	5	0.75	0.93	1.08	6.1	0.18	1.57	0.14	0.25	0.25	0.21	0.11	0.052			0.08		
	6	0.78	1.1	1.12	8.3	0.13	1.78	0.16	0.33	0.29	0.13	0.13	0.058	0.0025	0.0021		0.09	Ti:0.12
	7	0.53	0.71	1.34	5.99	0.22	1.82	0.01	0.21	0.09	0.08	0.03	0.031	0.0073	0.0033	0.08	0.12	
	8	0.63	1.95	0.81	7.39	0.11	1.40	0.31	0.01	0.39	0.18	0.11	0.082					
	9	0.66	0.55	1.18	6.83	0.17	1.73	0.49	0.001	0.42	0.25	0.15	0.145	0.0039	0.0065	0.06	0.04	Nb:0.12
	10	0.65	0.59	1.0	6.4	0.16	1.51	0.04	0.01	0.05	0.07	0.01	0.038					
	11	0.52	0.88	0.96	7.68	0.13	1.57	0.19	0.03	0.21	0.06	0.14	0.039	0.0009	0.0052			
	12	0.81	0.73	0.87	7.11	0.12	1.44	0.38	0.02	0.45	0.29	0.02	0.091					
	13	0.84	1.24	1.31	9.16	0.14	2.04	0.06	0.05	0.06	0.01	0.06	0.045	0.0006	0.0034			
	14	0.75	0.67	1.41	8.03	0.18	2.05	0.24	0.04	0.18	0.13	0.09	0.065	0.0031	0.0031			Ti:0.12
	15	0.79	1.15	1.47	7.31	0.20	2.05	0.43	0.01	0.30	0.18	0.04	0.124			0.11		
	16	0.58	0.68	1.41	8.03	0.18	2.05	0.46	0.05	0.34	0.1	0.07	0.103					
	17	0.78	0.51	1.09	10.55	0.10	1.93	0.42	0.001	0.39	0.04	0.08	0.125	0.0032	0.0096			Ta:0.08
	18	0.71	0.56	1.16	6.7	0.17	1.70	0.36	0.11	0.36	0.02	0.1	0.097					Zr:0.04
	19	0.67	2.01	0.84	8.55	0.10	1.52	0.32	0.09	0.43	0.04	0.04	0.119					
	20	0.69	1.09	1.14	9.72	0.12	1.92	0.44	0.01	0.39	0.03	0.13	0.141					

(continued)

		C (%)	Si (%)	Mn (%)	Cr (%)	Mn/Cr	Mn+ 0.08Cr (%)	Mo (%)	W (%)	(Mo+0.5W) /Mn	Ni (%)	V (%)	S (%)	Ca (%)	O (%)	Se+Te (%)	Pb+2Bi (%)	Nb+Ta+Ti+Zr (%)
Comparative Steel	1	0.71	1.03	0.98	2.02	0.49	1.14	0.06	0.01	0.07	0.09	0.11						
	2	1.02	0.24	0.75	5.22	0.14	1.17	0.93	0.05	1.27	0.12	0.31						
	3	1.43	0.35	0.41	11.89	0.03	1.36	0.96	0.33	2.74	0.14	0.33			0.0031			
	4	0.94	0.24	0.53	14.74	0.04	1.71	2.03	0.4	4.21					0.0021			
	5	2.11	0.35	0.51	13.89	0.04	1.62			0.00	0.21	0.15						
	6	1.04	0.22	0.76	0.73	1.04	0.82	0.76	0.01	1.01	0.22							
	7	1.06	0.31	0.45	0.21	2.14	0.47			0.00	0.14							
	8	0.87	0.24	0.41	0.12	3.42	0.42			0.00	0.21							
	9	0.88	0.28	1.18	0.53	2.23	1.22	0.2	0.03	0.18	0.21	0.34						
	10	0.85	0.38	2.03	1.04	1.95	2.11			0.00	0.11				0.003			
	11	1.02	0.44	1.09	0.48	2.27	1.13			0.00	0.12							

(A) Hardenability

[0083] A specimen of ϕ 3 mm × 10 mm was prepared and after holding it at the quenching temperature shown in Table 2 for 5 minutes, cooled to 100°C or less at a uniform cooling rate. The minimum limited cooling rate for obtaining a specimen hardness of HRC 58 or more with respect to each cooling rate when the cooling rate was varied is indicated as the hardenability.
[0084] Those having a slower limited cooling rate can be evaluated as having higher hardenability.
[0085] The hardenability necessary for the usage concerned is 15°C/min or less.

(B) Warpage after Heat Treatment

[0086] A specimen of 20 mm × 50 mm × 100 mm was prepared and after holding it at the quenching temperature shown in Table 2 for 30 minutes, quenched at the cooling rate shown for hardenability. Also, tempering was thereafter performed.
[0087] How high the specimen was warped after heat treatment with respect to the length of 100 mm was measured by a three-dimensional dimension measuring apparatus. Out of the length of 100 mm, the difference between maximum height and minimum height was determined, and the size of this difference per 100 mm was indicated.
[0088] In terms of accuracy in general, the size of the difference needs to be 0.1 mm or less. The difference in the state before heat treatment was set to 0.020 mm (0.020%) or less.

(C) Drill Machinability

[0089] A specimen of 50 mm × 50 mm × 200 mm was prepared and subjected to punching work by a steam-treated SKH51 HSS drill (ϕ 6 mm).
[0090] In the working, the punching work was repeated by changing the cutting rate under constant conditions of dry process, 0.15 mm/rev and bore depth of 15 mm until the drill was damaged by melting or breaking. The cutting rate was gradually decreased, and the cutting rate at which 70 or more bores were obtained was evaluated as the drill lifetime. A larger cutting rate indicates more excellent drill machinability.

(D) Grindability

[0091] A specimen of 20 mm × 50 mm × 200 mm was prepared and subjected to scraping work of scraping 0.5 mm from the surface of 50 mm × 200 mm by a flat grinding disc. Assuming that the working time of Comparative Example 6 is 100, the time necessary for 0.5 mm scraping was evaluated. When the time required is half, the grindability was rated 200. A larger numerical value indicates better grindability.

(E) Warpage after Working

[0092] After evaluating the grindability above, the difference between maximum height and minimum height out of the length of 100 mm was measured by a three-dimensional dimension measuring device. In terms of accuracy in general, the size of the difference needs to be 0.1 mm or less. The difference in the state before grinding work was set to 0.020 mm (0.020%) or less.

(F) Charpy Impact Test

[0093] The specimen was tested in accordance with the method described in JIS Z 2242. As for the specimen, a 10R notch specimen with a notch part of 10R and a depth of 2 mm was prepared. The test was performed at room temperature, and the value was evaluated by the impact value.

(G) Fatigue Test

[0094] The specimen was tested by the method described in JIS Z 2274. The specimen used was No. 1 specimen (parallel part: ϕ 8 mm) and the test was performed at room temperature. The strength causing no breakage when repeating the test 10^7 times was evaluated as a fatigue limit.
[0095] The results of these evaluations are shown in Table 2.

Table 2

		Quenching, °C	Tempering, °C	Hardness, HRC	Hardenability, °C/min	Warpage after Heat Treatment, % (per 100 mm)	Drill Machinability, m/min	Grindability, basis: 100	Warpage after Working, % (per 100 mm)	Charpy Impact, J/cm^2	Fatigue, N/mm^2
Steel of Invention	1	1030	100	64.9	7	0.003	24	150	0.008	82	950
	2	1030	230	63.1	8	0.008	33	175	0.005	52	920
	3	1040	240	61.3	8	0.013	31	175	0.003	50	910
	4	1030	300	60.3	7	0.008	28	175	0.013	60	920
	5	1040	400	58.9	9	0.007	45	225	0.013	46	910
	6	1050	500	58.8	10	0.007	49	200	0.003	80	980
	7	1010	480	59.8	9	0.011	56	200	0.007	45	930
	8	1010	190	62.8	9	0.011	31	150	0.011	53	900
	9	1030	200	62.8	6	0.013	58	200	0.01	85	980
	10	1030	500	61.3	8	0.007	29	175	0.008	59	900
	11	1030	490	59.4	8	0.011	32	150	0.007	51	920
	12	1030	520	58.1	7	0.008	30	150	0.008	55	910
	13	1040	220	61.9	10	0.01	34	175	0.011	52	920
	14	1050	200	63.1	10	0.008	31	150	0.008	81	980
	15	1030	230	60.8	11	0.005	49	225	0.005	51	920
	16	1020	180	61.4	10	0.013	29	150	0.01	51	910
	17	1010	190	62.3	9	0.003	26	150	0.007	98	970
	18	1050	140	63.4	8	0.01	35	175	0.011	73	960
	19	1020	510	60.1	7	0.007	29	175	0.007	48	910
	20	1020	180	62.7	9	0.005	32	150	0.013	56	910

(continued)

		Quenching, °C	Tempering, °C	Hardness, HRC	Hardenability, °C/min	Warpage after Heat Treatment, % (per 100 mm)	Drill Machinability, m/min	Grindability, basis: 100	Warpage after Working, % (per 100 mm)	Charpy Impact, J/cm^2	Fatigue, N/mm^2
Comparative Steel	1	1030	190	59.3	9	0.011	9	75	0.011	52	920
	2	1030	180	58.7	10	0.008	11	25	0.198	22	690
	3	1030	500	59.4	6	0.005	10	25	0.145	15	650
	4	1000	210	63.1	8	0.011	10	25	0.176	12	610
	5	960	190	58.9	10	0.007	5	25	0.211	13	680
	6	860	180	60.8	35	0.134	8	100	0.011	51	910
	7	810	100	63.1	50	0.111	10	100	0.007	48	910
	8	800	120	63.1	60	0.345	11	100	0.008	50	910
	9	830 (1030)	190	62.8 (45.8)	50	0.212	10	75	0.007	50	900
	10	850 (1010)	200	61.3 (44.9)	40	0.165	9	75	0.003	51	930
	11	800 (1000)	150	58.8 (50.3)	40	0.122	9	75	0.01	49	920

[0096] As seen from the results of Table 2, in Comparative Steel 1 where S is not added, the drill machinability is not satisfied.

[0097] In Comparative Steel 2 where the added amounts of C and Si greatly deviate from the ranges and also large amounts of Mo, W and V are contained, carbide is formed in a large amount and bad grindability and large warpage after working are exhibited. Furthermore, the property in terms of Charpy impact or fatigue is deteriorated due to carbide.

[0098] In Comparative Steels 3, 4 and 5 where Mn/Cr is too small and the added amount of C is out of the range, carbide is formed in a large amount and similarly to Comparative Steel 2, the properties are deteriorated.

[0099] In Comparative Steels 6, 7 and 8 where Mn/Cr is excessively large and Mn+0.08Cr is too small, hardenability is insufficient. Accordingly, rapid cooling is required for the cooling after quenching and the warpage after heat treatment becomes large. Also, in these comparative steels, a required hardness of HRC 58 or more is obtained only when the quenching temperature is less than 1,000°C.

[0100] In Comparative Steels 9, 10 and 11 where Mn/Cr is excessively large, hardenability is insufficient. Accordingly, rapid cooling is required for the cooling after quenching and the warpage after heat treatment becomes large.

[0101] Also, although a required hardness of HRC 58 or more is obtained when the quenching temperature is less than 1,000°C, a required hardness cannot be obtained when the quenching temperature is from 1,000 to 1,050°C.

[0102] Compared with these comparative steels, according to the steels of the present invention, good results are obtained with respect to all of the properties.

[0103] While the present 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 spirit and scope thereof.

[0104] The present application is based on Japanese Patent Application No. 2008-189726 filed on July 23, 2008 and Japanese Application No. 2009-091602 filed on April 3, 2009, the contents thereof being incorporated herein by reference.

Claims

1. A free-cutting alloy tool steel comprising, in terms of mass%:

    C: from 0.50 to 0.90%,
    Si: from 0.50 to 2.20%,
    Mn: 0.8% or more,
    Mn+0.08Cr: from 1.35 to 2.05%,
    Ni: from 0.01 to 0.30%,
    Mo+0.5W: from 0.01 to 0.50%,
    V: from 0.01 to 0.15%,
    S: from 0.03 to 0.15%,

    optionally comprising:

    Ca: 0.0100% or less,
    O: 0.0100% or less,
    Se+Te: 0.15% or less,
    Pb+2Bi: 0.15% or less,
    Nb+Ta+Ti+Zr: 0.15% or less,

    with the balance being Fe and unavoidable impurities,
    wherein the contents of Mn and Cr satisfy the following relationship:

    Mn/Cr: from 0.10 to 0.23,
    and the contents of Mo, W and Mn satisfy the following relationship:
    (Mo+0.5W)/Mn: 0.55 or less.

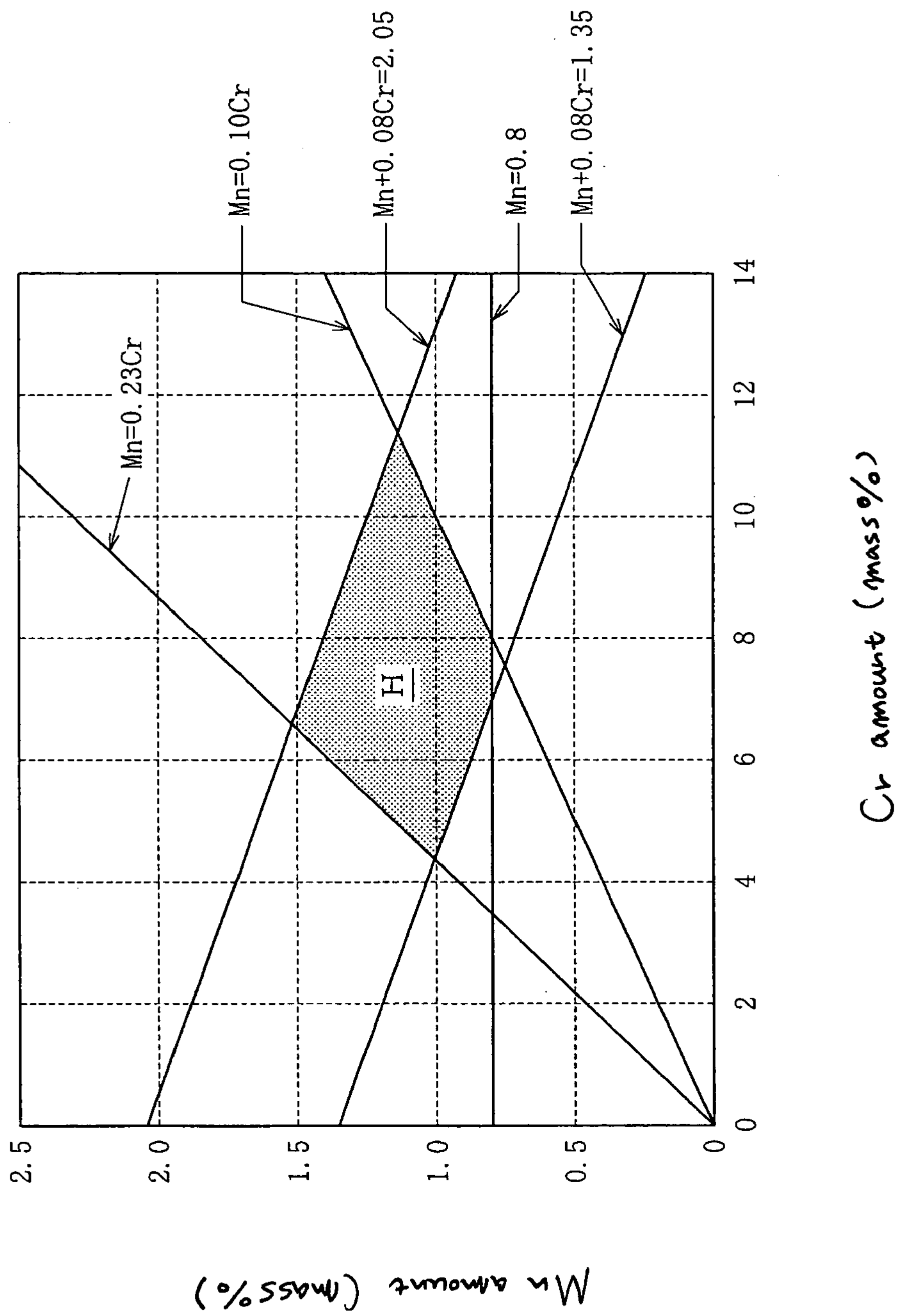
2. The free-cutting alloy tool steel as claimed in claim 1, which contains Ca in an amount of 0.0001% or more.

3. The free-cutting alloy tool steel as claimed in claim 1 or 2, which contains one or two combinations of, in terms of mass%,
    Se+Te: 0.01% or more, and
    Pb+2Bi: 0.01% or more.

4. The free-cutting alloy tool steel as claimed in one of claims 1 to 3, which contains one or more elements of Nb, Ta, Ti and Zr in an amount of, in terms of mass%,
Nb+Ta+Ti+Zr: 0.01% or more.

5. The free-cutting alloy tool steel as claimed in one of claims 1 to 4, which has been quenched at a temperature of 1000 to 1050°C.

Fig. 1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Mn=0. 8
Mn+0. 08Cr=1. 35
Mn=0. 23Cr
H
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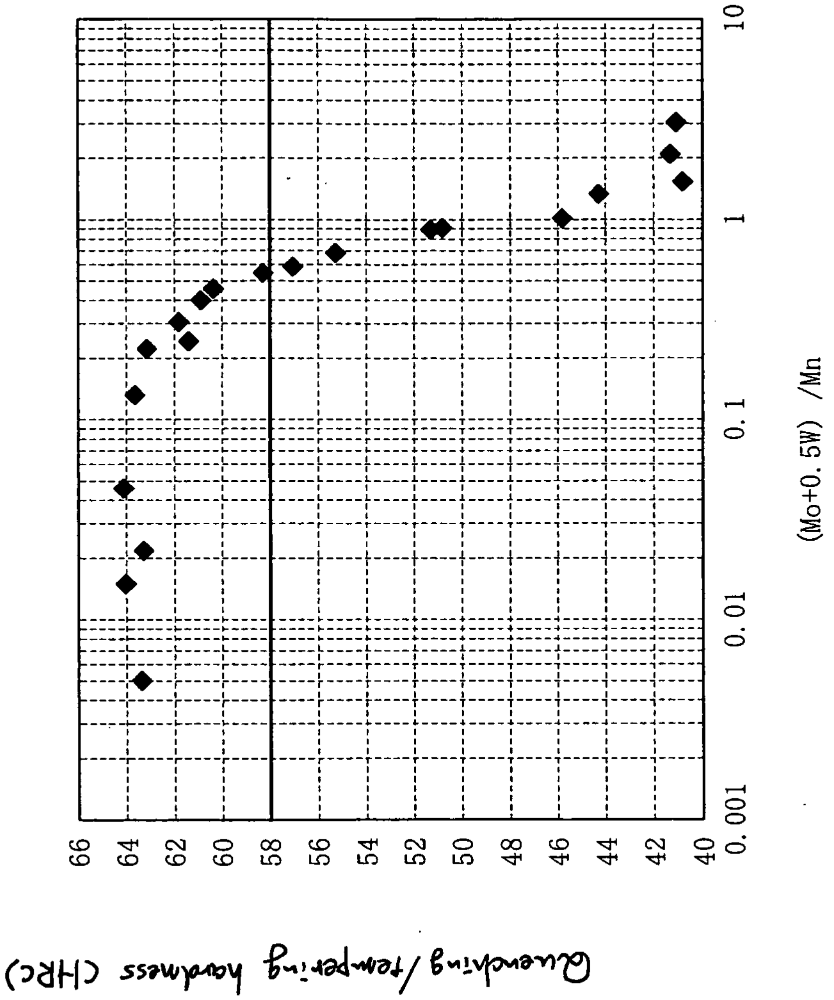
2
4
6
8
10
12
14
2.5
2.0
1.5
1.0
0.5
0
Cr amount (mass%)
Mn amount (mass%)

Fig. 2


(Mo+0.5W) /Mn
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0.01
0.1
1
10
66
64
62
60
58
56
54
52
50
48
46
44
42
40
Quenching/tempering hardness (HRC)

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EUROPEAN SEARCH REPORT

Application Number
EP 09 00 9568

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Place of search	Date of completion of the search	Examiner
Munich	13 October 2009	Badcock, Gordon

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